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RCRA FACILITY INVESTIGATION

DU PONT EXPERIMENTAL STATION

DRAFT FINAL REPORT

September 18, 1990

RCRA FACILITY INVESTIGATION
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DRAFT FINAL REPORT

Prepared for:

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September 19, 1990

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1 INTRODUCTION

1.1 PURPOSE

E.I. DuPont de Nemours & Co., Inc. (DuPont) entered into a Consent Order on February 15, 1989 with the U.S. Environmental Protection Agency - Region III (EPA) as operator and owner of the Experimental Station in Wilmington, Delaware. One requirement of the Order is to perform a RCRA Facility Investigation (RFI) for a portion of the site to determine fully the presence, magnitude, extent, direction, and rate of movement of any hazardous wastes and/or hazardous constituents from the area of investigation at the facility.

This report presents the procedures, results, and findings of data collection activities and data analysis performed for the RFI. The data have been compiled and integrated to fully characterize the environmental setting, source of contamination, nature and occurrence of contamination, and potential receptors. All data and supporting documentation for the findings of the RFI are included with this report. This document is submitted as a draft final version. A final version of the report will be prepared after comments are received from U.S. EPA (Region III).

1.2 OVERVIEW AND SCOPE OF WORK

The scope of work performed for the RFI is in accordance with the approved work plan and subsequent modifications proposed by DuPont and approved by EPA. The work consisted of: (1) review of available background information pertaining to waste handling at the facility; (2) field investigation to characterize source areas of contamination; (3) field investigation to characterize contaminant extent and movement within the environment; (4) analysis of the data collected; and (5) identification of potential receptors. The data collection program utilized several technologies.

The source area investigation used a phased approach. Soil-gas sampling was applied as a reconnaissance method to identify hot spots of soil contamination. Based on the results of soil-gas sampling, a Phase I soil sampling program was developed. In Phase I, hand auger and split-spoon sampling methods were used to collect samples. The samples were analyzed for volatile organic compounds (VOCs) and biphenyls. Selected samples were also analyzed for the full list of Appendix IX parameters.

Due to difficulties in collecting samples at most locations by auger techniques, a second set of soil samples was collected from test pits (Phase II sampling). Analytical results of Phase I samples indicated that semivolatile compounds were generally present in the soil at significant levels (relative to RCRA action levels) while VOC concentrations were relatively low (except at one location south of the present incinerator). Therefore, Phase II soil samples were analyzed for semivolatile compounds only. Again, selected samples were analyzed for Appendix IX constituents.

A background records review of potential contaminant sources is provided in Section 2. The procedures and results of the source area investigation activities are presented in Section 3. These results were used to characterize the environmental setting (Section 5) and to characterize the source of contamination (Section 6.1).

The investigation of contaminant occurrence and migration from source areas focused on two objectives: (1) characterization of the hydrogeologic system; and (2) determination of current groundwater and surface water quality. Field activities included:

- Fracture trace and structural analysis;
- Monitor well installation;
- Borehole surveys using geophysical and video techniques;
- Aquifer testing (slug tests, pumping tests, tracer tests);
- Groundwater monitoring (water-level and water-quality surveys); and
- Surface water and sediment sampling.

The data from these field activities were integrated to develop a conceptual model of groundwater flow at the site. A numerical analysis of the model was performed to identify migration pathways and receptors.

The procedures and results of the field program are presented in Section 4. The conceptual model and numerical analysis used to describe the hydrogeologic setting are presented in Section 5.2 and 5.3. Findings that pertain to contaminant characterization are discussed in Section 6.2.

2 GENERAL SETTING AND BACKGROUND REVIEW

2.1 SITE DESCRIPTION

The E.I. DuPont de Nemours & Company Experimental Station is located in New Castle County, Delaware, approximately four miles northwest of downtown Wilmington, Along Route 141. The facility is situated in the Brandywine Valley along the banks of the Brandywine Creek as shown in Figure 2.1. The Experimental Station is the central research and development facility for DuPont. The site has been active as a research facility for approximately 90 years. Prior to this, the area along the Brandywine Creek was used in the 1800s for gun powder manufacture by DuPont. Relic structures of these facilities are still in existence along the river front. Presently, the facility employs 5,000 chemists, engineers and technicians dedicated to product development and basic research.

The area of investigation is bounded by the Brandywine River to the south. Otherwise, the area is surrounded by property owned and controlled by DuPont.

2.2 SITE HISTORY

A brief chronology of site activities associated with the recent discovery of the soils and groundwater contamination follows:

Date	Event
May - July 1986	Utility excavation in the vicinity of Building 311 reveals the presence of soils and groundwater contamination. Duffield Associates, an environmental consultant, performs a study which includes the installation of monitor wells and soil and groundwater sampling. The State of Delaware and USEPA are informed of the findings.
April 1987	Utility excavation at the intersection of Creek and "C" roads reveals the presence of another area of soil contamination. Analysis of the site reveals that the problem is probably associated with backfill formerly placed at the site but obtained from the incinerator area.
May 1987	DuPont informs the USEPA about the problem.

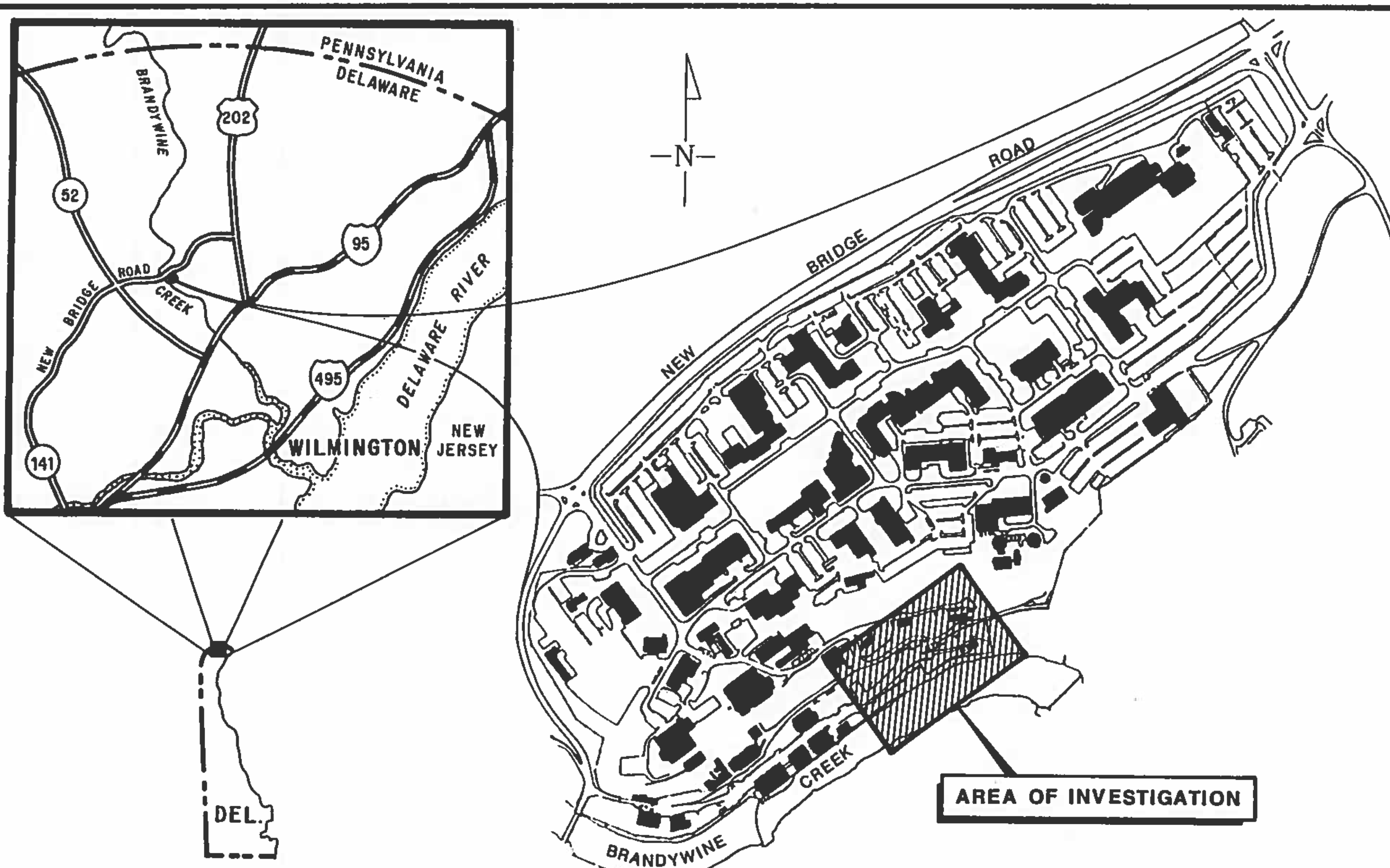

Figure 2.1. Location of the DuPont Experimental Station and the RFI area of investigation.

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June 1987	Contaminated soils from Creek Road area are removed from the site.
February 1989	Consent Order to conduct a RCRA Facility Investigation (RFI) at the site is signed.
December 1989	RFI begins.

In May 1986, a construction crew excavating adjacent to Building 311, DuPont's Hazardous Waste Incinerator, encountered dark stained soils which emitted an organic chemical odor. DuPont contracted a local Wilmington geotechnical firm, Duffield Associates, to perform an on-site reconnaissance for organic vapors using a HNu photo-ionization detector. On May 28 and June 2, 1986, Duffield recorded organic vapor concentrations in and around the excavation. Maximum HNu readings ranged from 100 to 150 ppm in the excavation around the stained soils.

DuPont conducted a file review to determine the possible source of the stained soils adjacent to Building 311. Based on pre-1946 Plant blueprints, a burning pit for the disposal of on-site waste was located in this area. This pit may have received waste up until 1946. Based on this information, DuPont believed that the soils possibly contained Dowtherm A, a low vapor pressure, heat exchange fluid. Dowtherm A is a mixture of diphenyl and diphenyl oxide manufactured by Dow Chemical. Additionally, the elevated HNu readings recorded at the excavation in May and June 1986 indicated that other more volatile compounds could also be present in the subsurface soils.

A plan to sample and analyze subsurface soils in the vicinity of the excavation was formulated by DuPont and Duffield Associates in June and July 1986. Eight test boring holes were attempted in the excavation vicinity. Due to the shallow depth to bedrock and the possible presence of subsurface materials such as boulders and gravel, only two of the borings (TB-C and TB-H) were able to penetrate more than three feet into the overburden and produce soil samples.

Chemical analysis of the soil samples from Area 1 indicated the presence of several volatile organic compounds and components of Dowtherm A. The soil sample from Test Boring TB-H (collected at a depth of 2.0 to 3.6 feet) had low levels of volatile organic compounds with tetrachloroethene (9.8 mg/kg) being the only volatile organic compound in excess of 1 mg/kg. TB-H was located approximately 40 feet west of the original excavation.

Two soil samples were collected from Test Boring TB-C at depths of 6-8 feet and 7.5-8.5 feet below ground surface. This boring was located adjacent to the original excavation. Several volatile organic compounds were detected in these soil samples. Aromatic hydrocarbons, such as ethyl benzene (10-35 mg/kg), toluene (4-11 mg/kg), total xylenes (34-80 mg/kg), cyclohexane (7-34 mg/kg), methylcyclohexane (2-10 mg/kg), and 1,1,2,2-tetrachloroethane (5-13 mg/kg), were detected. In addition, the components of Dowtherm A, diphenyl (72.8-77.3 mg/kg) and diphenyl oxide (215-223 mg/kg), were identified. The sampling locations, boring logs, and laboratory reports of the Area 1 samples were provided to EPA with the RFI work plan (dated July 1989).

Subsequent to the analysis of soil samples, four monitor wells were installed both upgradient and downgradient of Building 311 during October 1986. The lack of any saturated overburden soils indicated that groundwater flow was probably confined to bedrock fracture zones. Therefore, the monitor wells were drilled through the overburden and screened in competent bedrock. Groundwater samples were collected from the wells and analyzed for volatile organic compounds and Dowtherm A. The upgradient well, MW-1, showed no evidence of any contamination. However, the downgradient wells (MW-2, MW-3, MW-4) all contained some measure of volatile organic compounds or Dowtherm A. It was inferred from these data that the source of the groundwater contamination was the contaminated soils uncovered during the earlier investigation.

In April 1987, during the excavation of a water line along "C" Road, approximately 220 feet west-southwest of Building 311, discolored fill soil was discovered under a parking area (Area 2). Twenty-nine grab samples from the excavation were collected from depths of up to five feet below ground surface and analyzed for Dowtherm A, trichloroethene, and tetrachloroethane. In addition, five samples were submitted for a priority pollutant scan. Analysis of soil samples from the excavation indicated the presence of both volatile organic compounds and Dowtherm A. The results of the laboratory analysis were provided to EPA with the RFI work plan (dated July 1989).

Based on the chemical data and the physical appearance of the fill material, the material in this excavation appeared very similar to that found in the Building 311 excavation (Area 1). It was believed that backfill material from Area 1 was used during construction of the parking lot at Area 2.

DuPont contracted with O.H. Materials for additional excavation and disposal of visibly contaminated soils in Area 2. By June 1987, 180 cubic yards of material had been removed from the excavation. However, a HNu survey of the open excavation still detected organic vapor concentrations indicating that the full extent of the contaminated area had not been excavated. In July 1987, DuPont, in agreement with the USEPA, backfilled the excavation and decided to pursue additional investigation and remedial action for Area 2 in concert with the Area 1 investigation per a negotiated consent agreement with the USEPA.

2.3 <u>WASTE-HANDLING ACTIVITIES</u>

Review of the Experimental Station files and available aerial photographs revealed little detailed information about former site activities that may be associated with the contamination found. The only reference to possible original source areas is found on site blueprints from the 1940's. The pertinent information from these blueprints is compiled on Figure 2.2. One site blueprint of fire protection lines (Plate 1), dated September 9, 1941, identified three storage areas: oil storage 166; building 23 storage; and building 235 (burning enclosure). There are no available records to indicate what materials were stored in these areas; however, it is speculated that machine oil products were stored in building 166 and materials to be burned at the burning ground were stored in building 235 until transfer. Another site blueprint of a water supply lines (Plate 2), dated June 21, 1948, shows an area identified as a "burning ground" just south of the burning enclosure shown on the 1941 blueprint. The size of the burning ground, as shown on the blueprint, is approximately

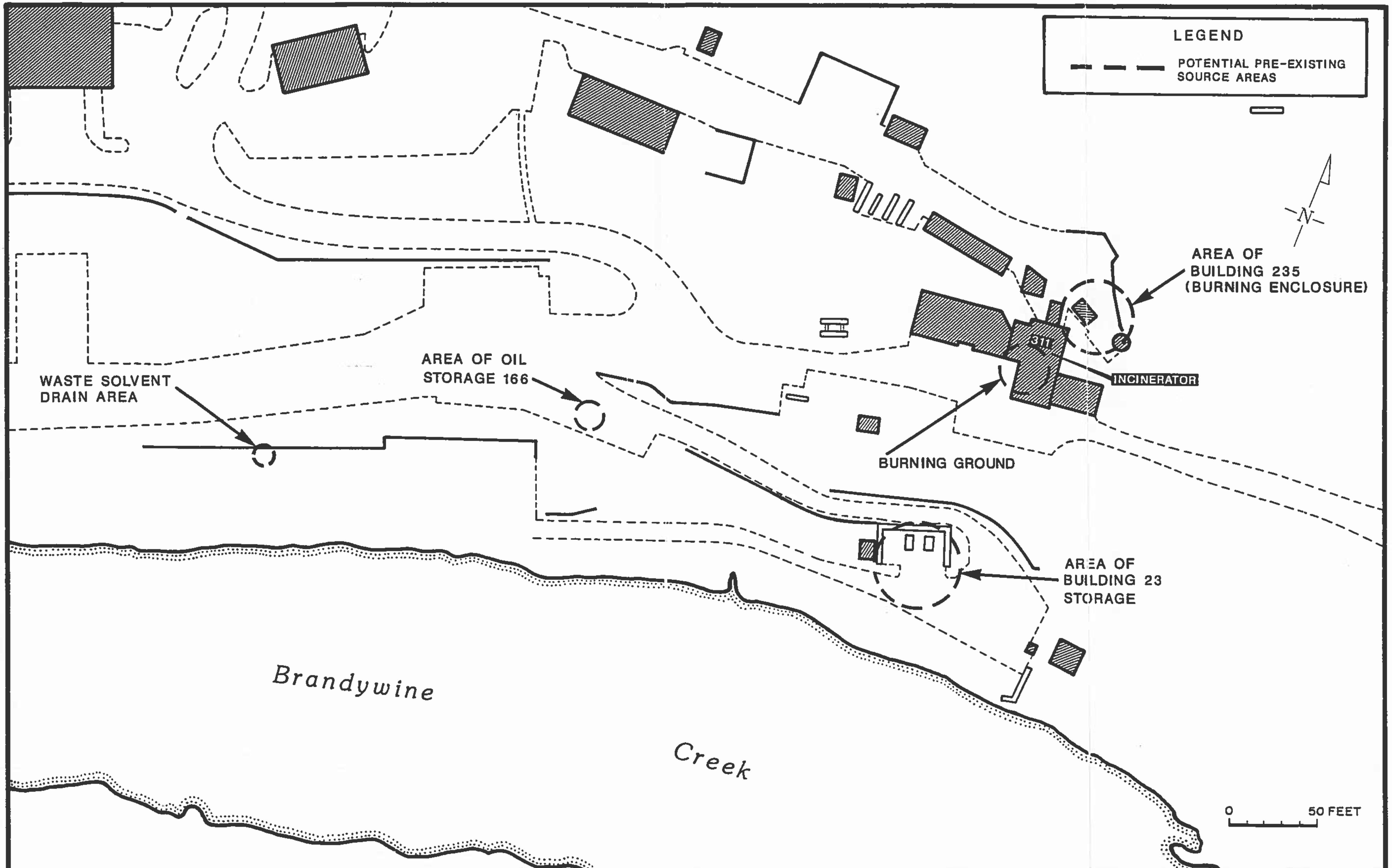

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Figure 2.2. General area of potential pre-existing source areas compiled from site archives.

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324 square feet, or 18 feet by 18 feet. Based on the available information in the files, the area was used as a burning area for solvents. Consequently, this area was a potential source for the current solids and groundwater contamination in the vicinity of the incinerator.

A base sewer and drainage map (Plate 3), originally dated November 17, 1948, and revised through November 19, 1974, provides a revision reference on February 12, 1959, of the inclusion of an "outside sewer drain inlet from chem burning area (former Bldg. 23)." However, Building 23 is identified only as a storage structure on the September 1941 blueprint. No other information exists on this building and there is no other information to indicate that a second burning area existed. It is believed that the revision reference contains a typographical error and is meant to identify the burning ground south of former building 235, not building 23.

There is also little information in the site files about the potential source area(s) for the soils and groundwater contamination located along Creek Road, approximately 400 to 500 feet west of the incinerator area. The September 1941 blueprint (Plate 1) shows several buildings in that area, but the only potential source feature identified is an oil storage structure.

According to site files, the contamination in the Creek Road area may be related to the placement of backfill material that may have consisted of ash and other fill material obtained from the old burning ground area. The filling of that area was probably associated with the demolition and removal of building 255, which apparently occurred sometime between 1948 and 1955, according to blueprint information.

3 FIELD INVESTIGATION OF SOURCE AREAS

3.1 SOIL GAS SURVEY

3.1.1 Introduction

On November 28 and 29, and December 5, 1989, TARGET Environmental Services, Inc. conducted a soil gas survey at the DuPont Experimental Station. A detailed report (prepared by TARGET) of the data collection procedures, analytical procedures, and results is provided in Appendix A. The discussion below summarizes the findings of that report.

3.1.2 Field Procedures

Soil gas samples were collected at a total of 45 locations at the site, as shown in Appendix A (Figure A-1).

To collect the samples, a ½-inch hole was advanced to a depth of approximately four feet by a drive rod. Where pavement was present, an electric hammer drill was employed for penetration prior to using the drive rod. Prior to sampling, the entire system was purged with ambient air drawn through a dust and organic vapor filter cartridge. A stainless-steel probe then was inserted to the full depth of the hole and sealed off from the atmosphere. A sample of in-situ soil gas was withdrawn through the probe and used to purge atmospheric air from the sampling system. A second sample of soil gas was withdrawn through the probe and encapsulated in a pre-evacuated glass vial at two atmospheres of pressure (15 psig). The self-sealing vial was detached from the sampling system, packaged, labeled, and stored for laboratory analysis.

All of the samples collected during the field phase of the survey were analyzed according to EPA Method 601 on a gas chromatograph equipped with an electron capture detector (ECD), but using direct injection instead of purge and trap.

3.1.3 Summary of Results

The primary volatile halocarbon detected at the site is trans-1,2-dichloroethene (t-1,2-DCE), and the highest concentrations (>100 μg/L) were observed in the northwestern portion of the surveyed area. More moderate concentrations (8-25 μg/L) occurred in the southeastern corner of the site. Moderate levels of tetrachloroethene (PCE) and trichloroethene (TCE) were also detected in these areas as well as areas south of the incinerator and along the western portion of Creek Road. A low-level anomaly of TCE (1-5 μg/L) occurred near the tanks at the northern end of the site. Very low levels (0.1-1 μg/L) of chloroform, 1,1,1-trichloroethane (1,1,1-TCA), carbon tetrachloride, and 1,1,2,2-tetrachloroethane (TECA) were present in scattered areas of the site.

3.2 SOIL SAMPLING

3.2.1 Phase I Sampling

3.2.1.1 Soil Sample Locations

Locations for Phase I soil sampling were based on the results of the soil gas survey (Section 3.1). Initially, twenty-two locations were selected for split-spoon sampling. An additional nine locations were selected for sample collection by hand auger in areas that were inaccessible to the auger rig (i.e., steep slope areas).

All of the proposed hand auger samples were successfully collected, however, only fifteen of the twenty-two proposed split-spoon locations were sampled due to the presence of cobbles or boulders. At these fifteen locations, ten were sampled by split spoon and the other five locations were sampled by hand auger. Therefore, a total of twenty-four locations were sampled; ten by split-spoon and 14 by hand auger. The final sample locations are shown on Figure 3.1.

3.2.1.2 Sampling Procedures

Phase I soil sampling was conducted from December 11-15, 1989 in the RFI area of investigation. Samples were collected either by hand auger or split spoon. Table 3.1 provides pertinent information regarding sample collection.

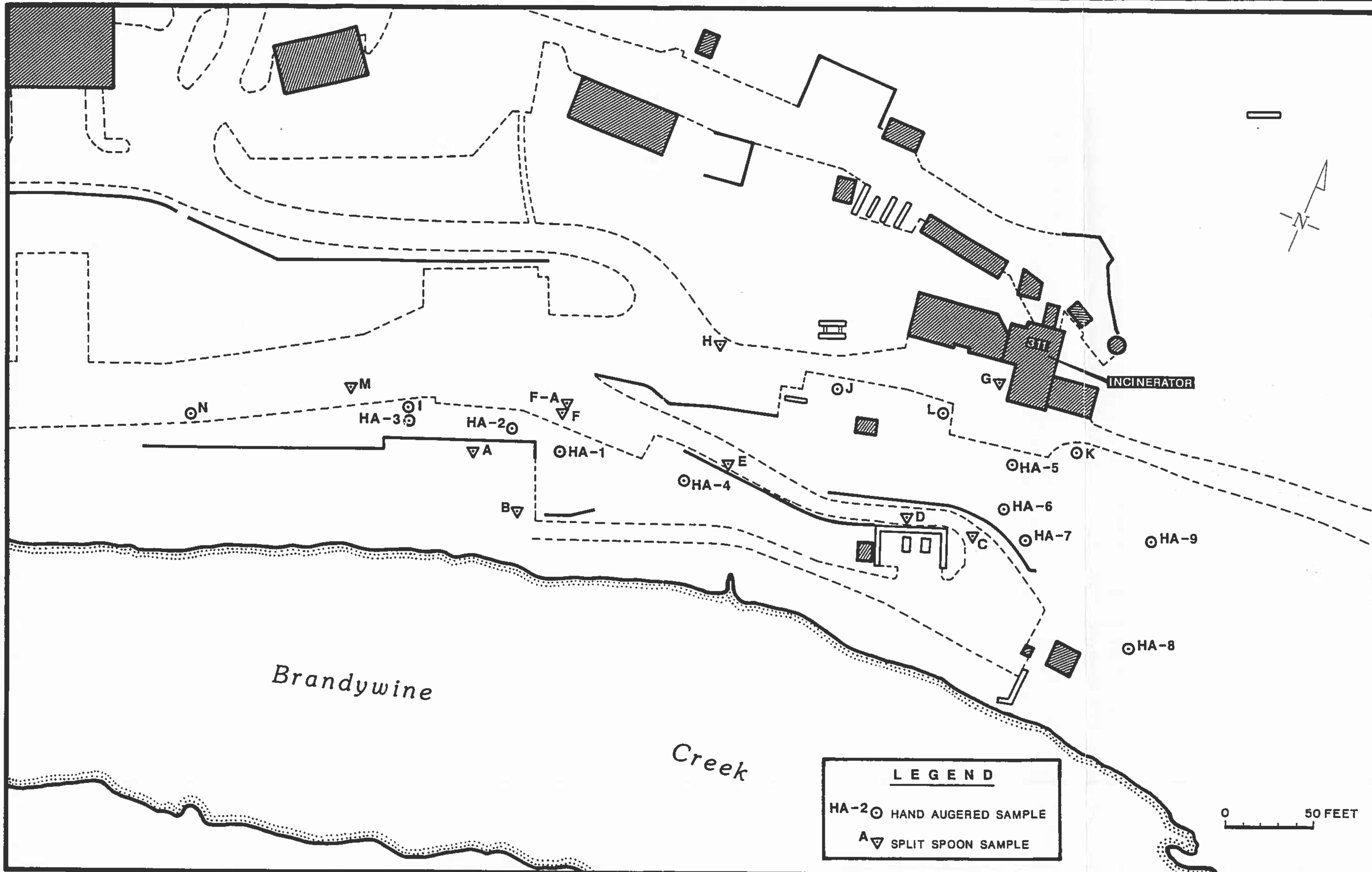

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Figure 3.1. Location of soil sample sites.

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Table 3.1. Record of soil samples.

Boring ID	Date of Completion	Method of Boring[1]	Total Depth of Hole (ft)	No. of Split Spoon Samples	Sample Depth (ft)	Remarks
A	12/12/89	D	2	1	0-2	
B	12/12/89	D	4	2	0-2	
					2-4	
C	12/12/89	D	2	1	0-2	
D	12/12/89	D	2	1	0-2	Insufficient recovery for complete sample
E	12/12/89	D	2	1	0-2	Insufficient recovery for complete sample
					2-4	
F	12/13/89	D	4	2	0-2	Insufficient recovery for complete sample
					2-4	
G	12/13/89	D	2	1	0-2	
HA-1	12/13/89	H	1.2	-	0-1.2	
HA-2	12/13/89	H	2.5	-	0-2.5	
HA-3	12/13/89	H	3.3	-	0-3.3	
HA-4	12/13/89	H	0.8	-	0-0.8	
HA-5	12/13/89	H	1.5	-	0-1.5	
HA-6	12/13/89	H	1	-	0-1	
HA-7	12/13/89	H	1.5	-	0-1.5	
HA-8	12/13/89	H	2.5	-	0-2.5	
HA-9	12/13/89	H	1.5	-	0-1.5	
H	12/13/89	D	2	1	0-2	
I	12/14/89	H	4	-	0-2	
					2-4	
J	12/14/89	H	1.5	-	0-1.5	
F-A	12/15/89	D	9	5	0-2	
					2-4	
					4-6	
					6-8	
					8-9	
K	12/15/89	H	2	-	0-2	Appendix IX spl.
L	12/15/89	H	1.5	-	0-1.5	
M	12/15/89	D	2	1	0-2	Appendix IX spl.
N	12/15/89	H	4	-	0-2	
					2-4	

[1]H = Hand Augered; D = Drilled

For samples retrieved by hand auger, the following procedures were used:

- At locations originally proposed for hand-auger sampling (HA-1 through HA-9), the auger was advanced to a maximum depth of 40 inches or refusal. One sample, recovered from the deepest zone, was placed immediately into sample jars, labeled, and placed in cold storage until shipment to the laboratory.
- At other hand-auger locations, originally planned as split-spoon locations (e.g., I, J, K, L, N), the auger was advanced to refusal. Samples were collected at 2-ft intervals. To collect a homogenized sample in a manner similar to the split-spoon technique, the sample was stored on a plastic sheet until the interval was completed (less than 10 minutes). A volume of sample, sufficient to fill the containers, was placed in a stainless steel bowl and gently mixed with stainless steel trowel. The sample was then placed in the containers, labeled, and placed in cold storage until shipment to the laboratory. It should be noted that samples were collected under near freezing or sub-freezing conditions that minimized volatilization. Therefore, it is unlikely that a significant loss of volatiles occurred due to handling the sample in this manner.

For samples retrieved by split spoon, borings were advanced using a hollow-stem auger. Split-spoon samples were collected at 2-ft intervals until refusal. The total depth of the boring and number of samples collected are shown in Table 3.1. After the amount of recovery was recorded and the sampled was logged for geology, a representative sample was obtained by collecting approximately equal amounts of sample along the spoon for each container. Once filled, the container was sealed, labeled, and placed in cold storage until shipment to the laboratory. Geologic logs, provided in Appendix B, indicate that underlying materials are relatively uniform in nature. In general, a dark grey to brown, clayey, gravelly fill overlies a silty, sandy clay with cobbles (weathered bedrock). The fill often contained anthropogenic materials including brick, glass, and slag.

Prior to startup at each sample location, all equipment in contact with the soils was thoroughly decontaminated. Small tools and split spoons were washed in a low-sudsing detergent, rinsed with clean tap water, and then given a final rinse with distilled water. Auger flights were washed at the sample site in the same manner, if only one flight was used (to save time). If multiple flights were used, they were taken to the on-site decontamination pad and steam cleaned. All washwater and rinse water at the sample site was collected in drums and disposed through the on-site waste treatment system.

Utility clearance and removal of asphalt were performed by an on-site subcontractor, Soft Dig (Delaware). A jack-hammer was used to break through the asphalt. The hammer cut only to the top of the roadbed material to prevent contact of the hammer with the fill or native soil.

Prior to mobilization at a new sample location, the completed boring was backfilled with clean fill dirt. The material removed from the boring, as well as all disposable equipment and disposable personal protective clothing, was placed in drums for storage until disposal at the on-site waste incinerator.

All work was conducted in Level D personal protective clothing and equipment. Attempts were made to monitor air quality with an Organic Vapor Analyzer (OVA), however; ambient temperatures were always less than 10°C (50°F), which is the minimum operating temperature for the instrument. Therefore, the readings, which varied between 0-15 ppm calibrate gas equivalent (CGE), are not considered meaningful.

3.2.1.3 Sample Analysis

All soil samples collected under Phase I were analyzed for Volatile Organic Compounds (VOCs), biphenyl, and biphenyl oxide with the following exceptions:

- The sample collected at boring K was analyzed for Appendix IX compounds in addition to biphenyl and biphenyl oxide. A separate VOC analysis was not performed because these compounds are included in the Appendix IX suite.

- The sample collected at boring M was analyzed for Appendix IX compounds only. Sample recovery was not sufficient for an additional analysis of biphenyl and biphenyl oxide.

- The VOC container for sample collected at boring D was only half full due to insufficient sample recovery.

- The sample collected at boring F was analyzed for VOCs only. Sample recovery was not sufficient for an additional analysis of biphenyl and biphenyl oxide.

It should also be noted that due to the lack of sample recovery, duplicates could not be collected for any sample. One trip blank and one field blank were collected each day of sampling.

3.2.1.4 Limitations of Sampling Methodology

With the exception of boring F-A (total depth 9 ft), the borings could not be advanced past a maximum depth of 4 ft. The presence of large cobbles and boulders prevented penetration by the augers. Additionally, sample recovery was poor. After ten borings had been completed, Phase I soil sampling was stopped to reassess the sampling technique. Subsequently DuPont project staff met with EPA representatives to propose an alternative technique that involved excavation and sampling of test pits, which would allow sampling of the overburden at greater depths. This technique was approved and applied under the Phase II soil sampling activity described below.

3.2.2 <u>Phase II Sampling</u>

3.2.2.1 Sample Locations

The locations of test pits excavated for Phase II sampling are shown in Figure 3.2. In general, test pits were placed in areas that were not sampled during Phase I. One exception is pit TP-7, located over boring C. The sample from this boring showed the highest concentration of VOCs (refer to Section 3.2.3). Therefore, TP-7 was installed to obtain a more extensive characterization of this area with respect to soil quality.

General areas for test pits were identified first. A utility survey of these areas then was completed. Final test pit locations were selected based on this survey. An area of approximately 12 ft by 6 ft was cleared for each test pit.

3.2.2.2 Sampling Procedures

Phase II soil sampling was conducted from March 10-12, 1990. The pits were excavated by Keshaw Construction Company (Delaware) with a backhoe. Most pits were located in areas overlain by asphalt. Prior

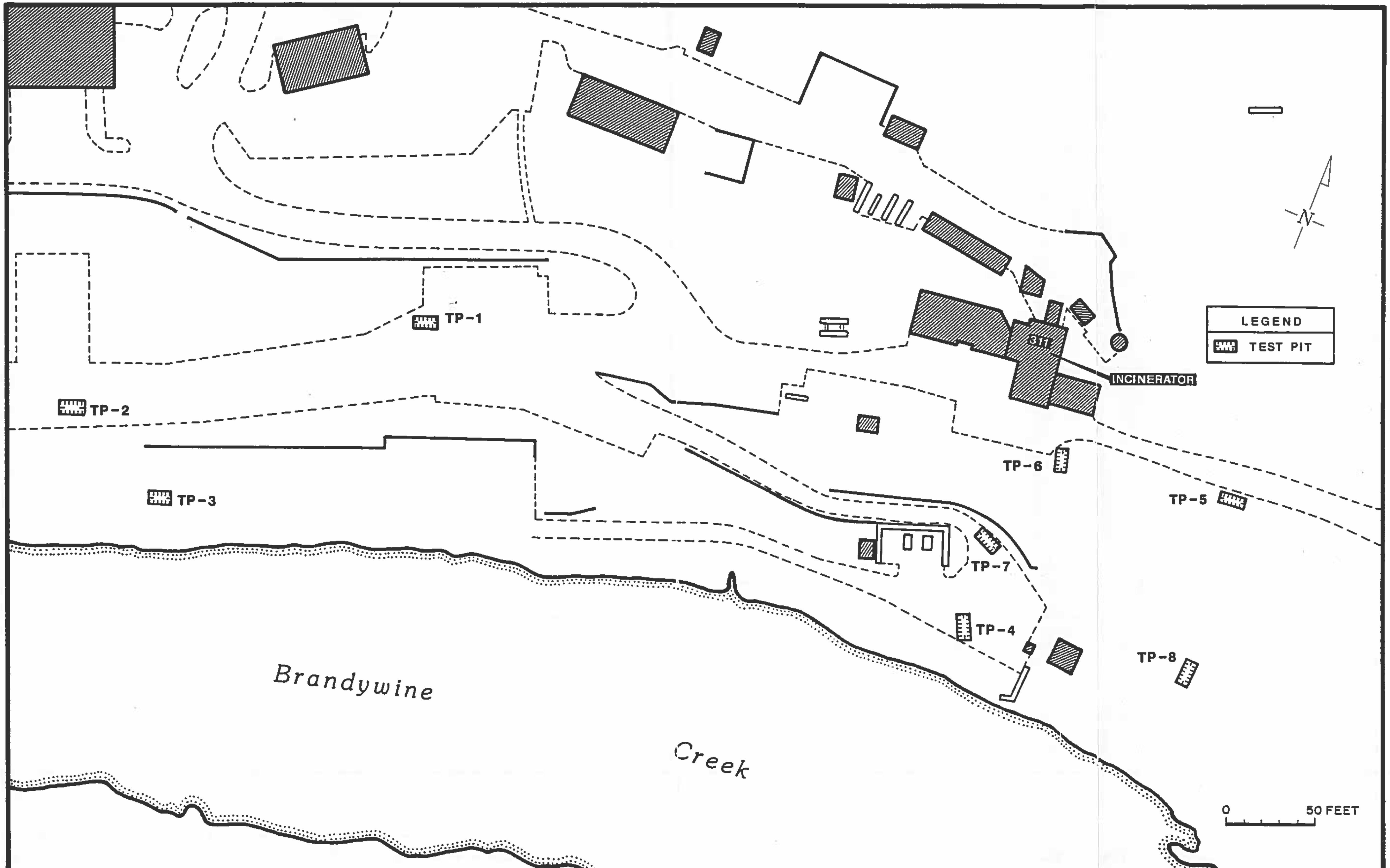

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Figure 3.2. Location of test pit sites.

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to excavation, the asphalt was cut along the outline of the pit area with a jackhammer. Background readings for air monitoring instruments were taken at this time. Additionally, a plastic liner was laid out beside the pit area to receive excavated materials.

The excavation proceeded as follows:

- The pit was excavated to a depth of four feet or refusal, whichever came first. Each bucket of soil was inspected by the onsite geologist. FID (OVA) and PID (HNu) meters were used to monitor both the excavated materials and the open pit for organic vapors. Soil characteristics (e.g., texture, anthropogenic materials) were noted on field forms.

- If refusal had occurred, two samples were collected from different horizons (if possible) in the pit. Otherwise one sample was collected and the excavation proceeded as above to a maximum depth of 8 feet.

- During excavation, the removed materials were segregated, based on visual inspection and air monitoring, to separate clean and suspect fill materials. The asphalt, removed prior to excavation, also was placed separate from the fill materials.

- After excavation was terminated, the pit dimensions were measured and the subsurface materials were logged by the on-site geologist.

- Once the excavation and sampling were completed, the pit was backfilled with the designated clean material. Backfilling was completed with clean fill dirt provided by Kershaw. The suspect materials were drummed and stored on site until sample results were provided. These materials were then disposed off site. The asphalt was disposed of in on-site, construction waste dumpsters.

Soil samples were collected as a composite from all accessible sides of the pits. Based on visual inspection, sample horizons that appeared most disturbed or potentially contaminated were selected. Generally, the sample was retrieved using clean shovels and stainless-steel spoons. The surface material was scraped away before the sample was collected. The soil was placed temporarily in a stainless-steel bowl. For five samples, TP-1B, TP-2B, TP-5B, TP-6B, and TP-6BD, soil was collected by the backhoe and samples were taken directly from the bucket. In these cases, the sample horizon was too deep for the sampler to reach from the ground surface. After large rock fragments were separated out, sample jars were filled, labeled and placed in iced coolers for storage until shipment to the laboratory.

A total of 22 soil samples were collected from eight pits. These included six duplicate samples. Additionally, one equipment rinseate blank was collected each day. The samples were shipped each day to York Laboratories (New Jersey). A trip blank was included with each shipment. Table 3.2 summarizes the sample information.

Test pit logs (provided in Appendix B) are consistent with the descriptions provided in the Phase I boring logs. Multiple fill layers are present (often containing anthropogenic materials such as brick, concrete, glass, cinders) with a matrix of silty clay with cobbles and boulders. Ash layers were identified in pits TP-2, TP-3, TP-4, and TP-6.

Prior to mobilization at each pit location, all equipment in contact with the soils was thoroughly decontaminated. Sampling tools and bowls were washed in a low-sudsing detergent and rinsed with distilled water. The backhoe arm and bucket were steam-cleaned at the on-site decontamination pad. All washwater and rinse water was disposed through site drains connected to the wastewater treatment system.

All work was conducted in Level D personal protective clothing and equipment. No readings above background were measured by either the OVA or the HNu instruments.

3.2.2.3 Sample Analysis

All but one soil sample was analyzed for Priority Pollutant Base Neutral Compounds (PP BNA) plus biphenyl and biphenyl oxides. Sample TP-2A was analyzed for Appendix IX compounds only and TP-7A was analyzed for both Appendix IX and PP BNA compounds plus biphenyl and biphenyl oxides. The record of sample analysis is shown in Table 3.2.

Table 3.2. Record of test pit samples.

Test Pit ID	Date of Completion	Total Depth (ft)	No. of Samples	Sample ID	Sample Depth (ft)	Analysis[1]
TP-1	03-10-90	5.5	2	TP-1A/TP-1AD	0 - 4	BNA, B/BO
				TP-1B	4 - 5.5	BNA, B/BO
TP-2	03-10-90	8.0	2	TP-2A	1.1 - 1.6	APPENDIX IX
				TP-2B	7 - 8	BNA, B/BO
TP-3	03-10-90	3.6	2	TP-3A/TP-3AD	0.5 - 2	BNA, B/BO
				TP-3B/TP-3BD	2 - 3.7	BNA, B/BO
TP-4	03-10-90	3.3	2	TP-4A	1.5 - 3.5	BNA, B/BO
				TP-4B	5.6 - 7	BNA, B/BO
TP-5	03-11-90	8.0	2	TP-5A	0 - 4	BNA, B/BO
				TP-5B	4 - 8	BNA, B/BO
TP-6	03-11-90	7.5	2	TP-6A/TP-6AD	0 - 4	BNA, B/BO
				TP-6B/TP-6BD	4 - 7.5	BNA, B/BO
TP-7	03-11-90	1.5	1	TP-7A	0.9 - 1.5	APPENDIX IX, BNA, B/BO
TP-8	03-12-90	4.5	2	TP-8A	0 - 1.5	BNA, B/BO
				TP-8B	1.5 - 4.5	BNA, B/BO

[1] BNA - Priority Pollutant Base Neutral Compounds
B/BO - Biphenyl/Biphenyl Oxides

3.2.3 Results of Phase I and Phase II Soil Sampling

The results of Phase I and Phase II laboratory analysis are summarized in Table 3.3 and 3.4 and plotted on Figure 3.3, 3.4, and 3.5. Data summary packages of the laboratory reports are provided in Appendix G. These packages were prepared by a quality assurance specialist, who performed validation on at least 10% of the samples (as per USEPA, Region III/DuPont agreement) in addition to compiling the data.

The compounds detected in the VOC fraction are similar to those detected by the soil gas survey. These analytes include trichloroethylene, tetrachloroethylene, trans-1,2,-dichloroethene, methylene chloride, toluene, 1,1-dichloroethene, ethyl benzene, and 1,1,2-trichloroethane. Total VOC concentrations are less than 1 ppm at all locations except soil boring site C.

Total BNA concentrations (semi-volatile compounds) vary widely across the site. The analytes detected in samples at a concentration greater than 1 ppm, include: pyrene, fluoranthene, phenanthrene, benzo(k)fluoranthene, benzo(a)anthracene, chrysene, benzo(a)pyrene, benzo(b) fluoranthene, indeno(1,2,3-cd)pyrene, anthracene, Di-n-butylphthalate, benzo(g,h,i)perylene, naphthalene, acenaphthylene, acenaphthene, and fluorene. The highest BNA concentrations are associated with samples collected from horizons that were visually observed to contain anthropogenic fill or ash (TP-2, TP-4, and TP-6). Samples collected above or below these horizons generally show a total BNA concentration that is two orders of magnitude lower. This suggests that soil contamination is confined to discrete horizons. The biphenyl portion of the semivolatiles at each sample location is generally less than 100 ppb. The highest concentration observed is 830 ppb at test pit TP-4.

No herbicides, sulfides, cyanides, or dioxins/furans were reported for any of the four Appendix IX samples. Small quantities of certain pesticides/PCBs (total reported in four samples ranged from 6-618 ppb) were observed. The analytes included chlordanes, 4,4'-DDE, 4,4'-DDT, and heptachlor.

Table 3.3. Total volatile organic compounds and semivolatile compounds biphenyls in soils.

Boring or Test Pit ID	Sample No.	Sample Interval (ft-ft)	Total VOCs (ppb)	Total Semi-volatiles[1] (ppb)	Biphenyl/Biphenyl Oxide (ppb)
A	A-2	0-2	44		89
B	B-2	0-2	59		ND
B	B-4	0-4	42		ND
C	C-2	0-2	48,440		98
D	D-2	0-2	192		14
E	E-2	0-2	275		ND
F	F-2	0-2	80		NS
F	F-4	2-4	72		ND
G	G-2	0-2	63		ND
HA-1	HA-1	0-1.2	ND		27
HA-2	HA-2	0-2.5	18		ND
HA-3	HA-3	0-3.3	11		ND
HA-4	HA-4	0-0.8	ND		ND
HA-5	HA-5	0-1.5	34		59
HA-6	HA-6	0-1	87		67
HA-7	HA-7	0-1.5	111		101
HA-8	HA-8	0-2.5	8		ND
HA-9	HA-9	0-1.5	21		30
H	H-2	0-2	50		25
I	I-2	0-2	168		ND
I	I-4	2-4	227		ND
J	J-1.5	0-1.5	301		61
F-A	F-2A	0-2	64		ND
F-A	F-4A	2-4	262		ND
F-A	F-6A	4-6	235		ND
F-A	F-8A	6-8	101		27
F-A	F-9A	8-9	206		86
K	K-2	0-2	107.9[2]	9,064[2]	11
L	L-1.5	0-1.5	41		10
M	M-COMP	0-2	73.7[2]	1,661[2]	ND
N	N-2	0-2	97		22
N	N-3	2-4	42		ND
TP-1	TP-1A	0-4		29	ND
TP-1	TP-1AD	0-4		31	ND
TP-1	TP-1B	4-5.5		ND	ND

[1] Includes biphenyl/biphenyl oxides
[2] Appendix IX analysis
NS - No Sample
NA - Not Applicable
ND - Not Detected

Table 3.3. (Continued).

Boring or Test Pit ID	Sample No.	Sample Interval (ft-ft)	Total VOCs (ppb)	Total Semi-volatiles[1] (ppb)	Biphenyl/Biphenyl Oxide (ppb)
TP-2	TP-2A	1.1-1.6	31[2]	41,872[2]	NA
TP-2	TP-2ARE	1.1-1.6		49,630[2]	NA
TP-2	TP-2B	7-8		257	ND
TP-3	TP-3A	0.5-2		18	ND
TP-3	TP-3AD	0.5-2		22	ND
TP-3	TP-3B	2-3.7		66	ND
TP-3	TP-3BD	2-3.7		87	ND
TP-4	TP-4A	1.5-3.5		423	ND
TP-4	TP-4B	5.6-7		454,060	860
TP-5	TP-5A	0-4		4,167	ND
TP-5	TP-5B	4-8		184	ND
TP-6	TP-6A	0-4		247	17
TP-6	TP-6AD	0-4		206	12
TP-6	TP-6B	4-7.5		72,249	110
TP-6	TP-6BD	4-7.5		28,564	35
TP-7	TP-7A	0.9-1.5		3,536	118
TP-7	TP-7AD	0.9-1.5		5,327	19
TP-7	TP-7A	0.9-1.5		2,814[2]	NA
TP-8	TP-8A	0-1.5	386[2]	4,421	12
TP-8	TP-8B	1.5-4.5		468	ND

[1] Includes biphenyl/biphenyl oxides
[2] Appendix IX analysis
NS - No Sample
NA - Not Applicable
ND - Not Detected

Table 3.4. Metals in soil.

	Concentration (ppm)			
Parameter	M-COMP	K-2	TP-2A	TP-7A
Antimony	ND	ND	ND	ND
Arsenic	3.8	3.6	7.2	2.4
Barium	146	154	134	87.7
Beryllium	ND	ND	0.41	0.15
Cadmium	1.22	1.37	3.8	0.48
Chromium	49.4	33.4	24.4	21.4
Colbalt	15.9	10.8	6.5	11.7
Copper	35.5	173	34.3	62.8
Lead	29.3	73.5	38.9	8.7
Mercury	0.47	2.48	3	0.36
Nickel	26.6	30.1	18.8	19.7
Selenium	ND	ND	0.5	0.68
Silver	ND	2.21	ND	ND
Thallium	ND	ND	ND	ND
Tin	ND	ND	ND	ND
Vanadium	55.3	26.4	28.4	57.3
Zinc	160	165	69.6	110

ND - Not detected

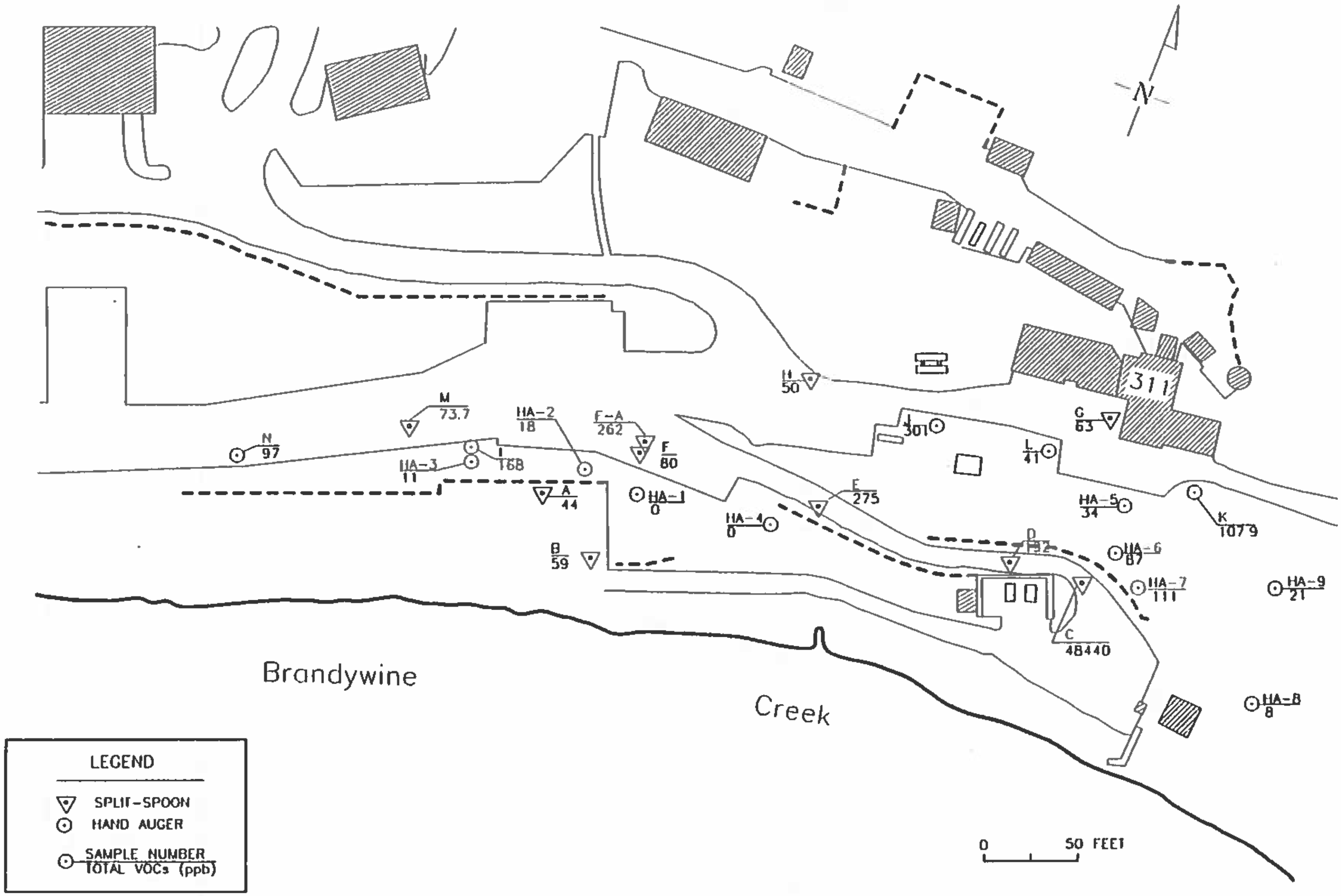

Figure 3.3. Total volatile organic compounds in soils (ppb) from Phase I and Phase II sampling.

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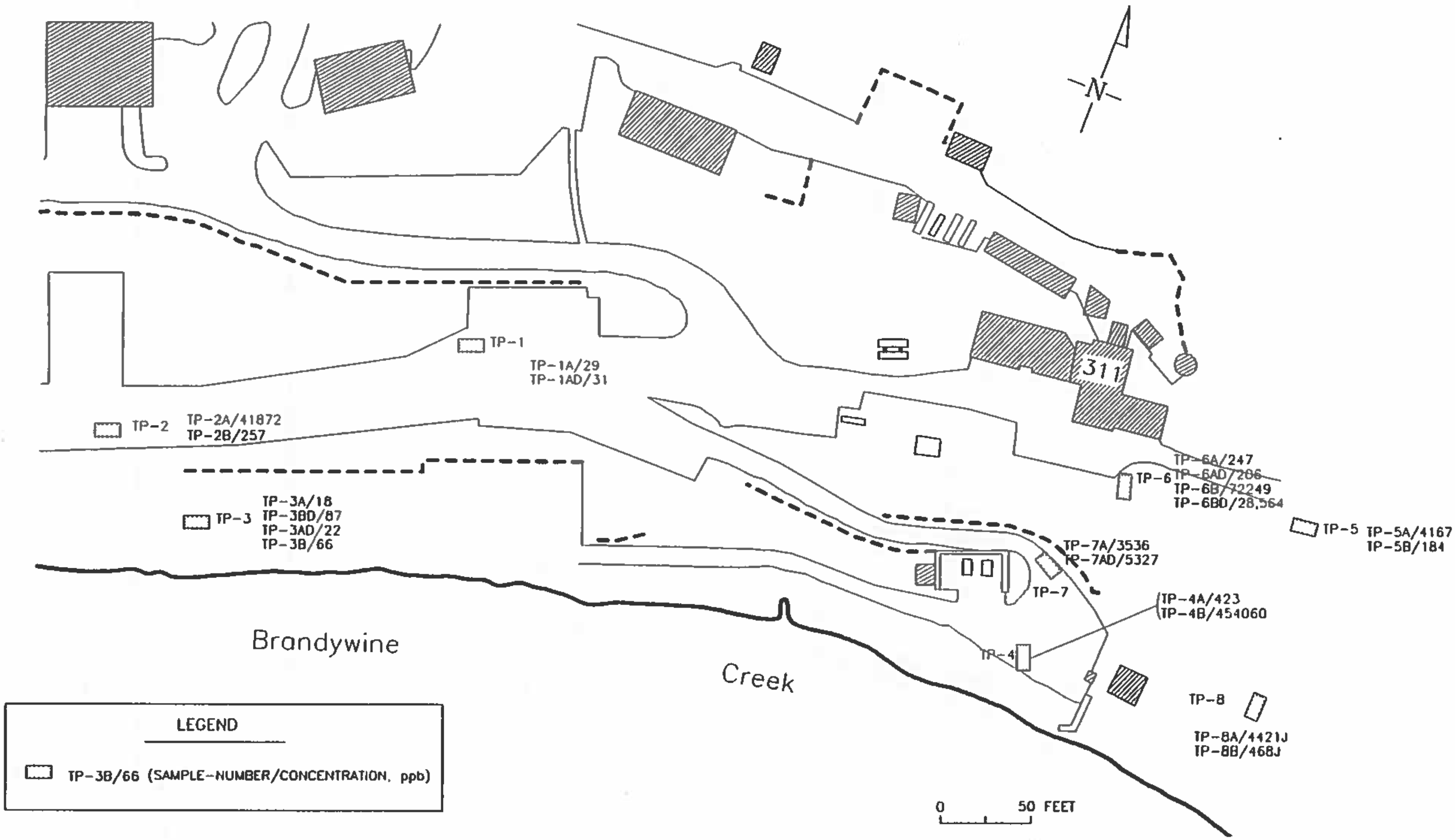

Figure 3.4. Total semivolatile compounds in soils (ppb) from Phase I and Phase II sampling.

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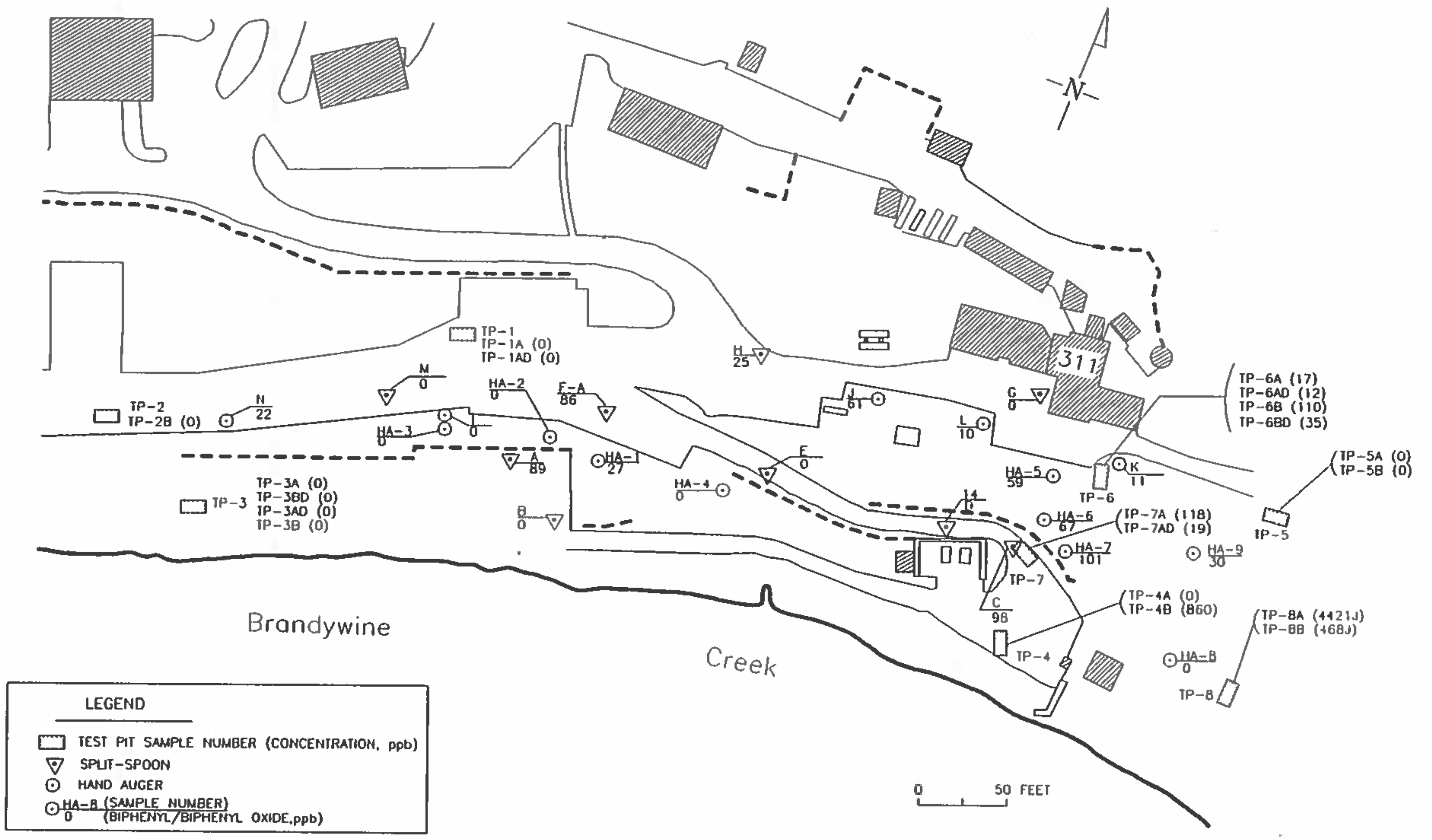

Figure 3.5. Biphenyl/Biphenyl Oxide in soils (ppb) from Phase I and Phase II sampling.

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P8788-016/OA/21

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The concentration of metals detected in soil samples (Table 3.4) is generally low relative to EPA RCRA action levels. One exception is sample TP-2A which shows a Beryllium concentration of 0.41 mg/Kg (RCRA action level is 0.20 mg/Kg).

4 FIELD INVESTIGATION OF CONTAMINANT EXTENT AND MIGRATION

4.1 FRACTURE TRACE/STRUCTURAL ANALYSIS

4.1.1 General

The objective of performing the fracture trace/structural survey in the vicinity of the DuPont Experimental Station was to identify the frequency and orientation of fractures (predominantly joints) in the bedrock outcrops around the site. These fractures may serve as contaminant flow pathways at the site. Additionally, this information was to aid in the placement of monitor wells on the site for development of an effective groundwater monitoring network.

The fracture trace/structural survey consisted of the evaluation of available aerial photographs and available regional information, and field measurement of rock outcrops in the vicinity of the site.

4.1.2 Regional Structural Geology

The DuPont Experimental Station is located within the Appalachian Piedmont Province. The site is situated on the Paleozoic age Wilmington Complex (Woodruff and Thompson, 1975). The rocks of this unit consist of banded gneiss; including felsic bands of quartz and andesine, and mafic bands of calcic plagioclase, pyroxenes, and hornblende.

It has long been recognized that a widespread brittle, structural fabric is overprinted on Paleozoic-age ductile structures in the Appalachian Piedmont. Previous studies (Dressel, 1989; Howard, 1986; Thompson, 1983; Thompson and Hager, 1979; Newell and Wise, 1964) have investigated various aspects of the relationship between lineaments, joints, seismicity, and stream morphology in the Piedmont. Brittle structural features present in the Piedmont include foliation, faults, and joints. Additionally, the emplacement of Mesozoic-age intrusive dikes is most likely controlled by the brittle structural fabric in the Piedmont.

The igneous dikes in the Piedmont consistently trend in a northeasterly direction with a mean azimuth of 36° (Thompson, 1983).

The emplacement of the dikes is apparently the result of northwest-southeast-oriented horizontal extension related to the opening of the Atlantic Ocean. There appears to be a strong parallelism between the orientation of lineaments and the Mesozoic-age dikes in the Piedmont of Delaware and adjacent southeastern Pennsylvania.

A study of known or probable faults in the Delaware Piedmont (Thompson, 1983) indicates that most trend in an east-northeasterly direction. Although the mean azimuth of the faults does not correlate to the mean azimuth of lineaments, one group of faults (0-40°) does coincide with the mean azimuth of the lineaments (24°; Dressel, 1989). It has been suggested that the lineaments reflect brittle structures that in some way focus local seismicity.

Four joint azimuth peaks in the Piedmont of Delaware and southeastern Pennsylvania have been recognized (Dressel, 1989). Two peaks are predominant and fall within the intervals of 020-030° and 350-010°. Two lower-order peaks fall within the intervals of 270-280° and 290-330°. The dips of most joints are vertical in orientation. It is likely that the joints developed both from compressive stresses associated with the last phase of Appalachian Mountain building and extension stresses associated with the opening of the Atlantic Ocean in the Mesozoic Era.

Dressel (1989) noted that although there was a general similarity between the azimuthal distribution of lineaments and that of joints, there was not a lineament-azimuth peak counterpart of the broad northwest-trending joint-azimuth peak.

On the contrary, there appears to be a very strong parallelism between the orientation of joints and linear stream segments in the Piedmont of Delaware and adjacent Pennsylvania. It is probable that the joint system controls the pattern of drainage.

4.1.3 Fracture Trace Mapping

Aerial photographs available for the area from local sources (United States Department of Agriculture, Soil Conservation Service, New Castle County) were reviewed for fracture-trace mapping purposes. The photographs available from these sources are low-altitude photographs that were obtained for soil mapping purposes. Aerial photography from 1937, 1954, 1962, 1968, 1977, and 1982 were analyzed for the presence of lineaments that are conspicuous tonal and/or physiographic features of a linear nature. Tonal lineaments are represented by contrasts in textures or tint while physiographic lineaments are represented by anomalously linear stream valleys or ridges.

The identification of "natural" lineaments in the vicinity of the site is complicated because of the urbanization of the area. The site has been active as a manufacturing/research facility for over 100 years; therefore, the land surface shown in available photographs has been extensively modified by the construction of roads and buildings. This makes the recognition of natural tonal and physiographic features very difficult. Consequently, no major lineaments were identified in these aerial photographs. However, some lineament mapping information is available from other, more remote, sources.

Dressel (1989) completed the most extensive mapping of lineaments in the Delaware Piedmont using LANDSAT-4 Band 2/Band 4 Thematic Mapper Imagery and Natural High Attitude Program Photography. The lineaments mapped by Dressel (1989) in the immediate vicinity of the DuPont Experimental Station are shown in Figure 4.1.

Of the three lineaments depicted, the one coincident with a reach of the Brandywine Creek was discussed in detail by Dressel (1989). This lineament, known as the Brandywine/Hagley lineament, is approximately 3 km in length and is composed of both a physiographic segment (coincident with the Brandywine) and a tonal segment extending to the southwest. Dressel recognized two joint sets centered at 022° and 285° in five outcrops located along the trace of the lineament. Dressel recognized that the 022° joint set was nearly parallel to the azimuth of the Brandywine/Hagley lineament (029°). The 285° joint set was also recognized to be nearly parallel to the section of the Brandywine Creek located immediately upstream. Based on this evidence, as well as other evidence in the Delaware Piedmont, Dressel (1989) concluded that stream morphology was probably controlled by joint patterns.

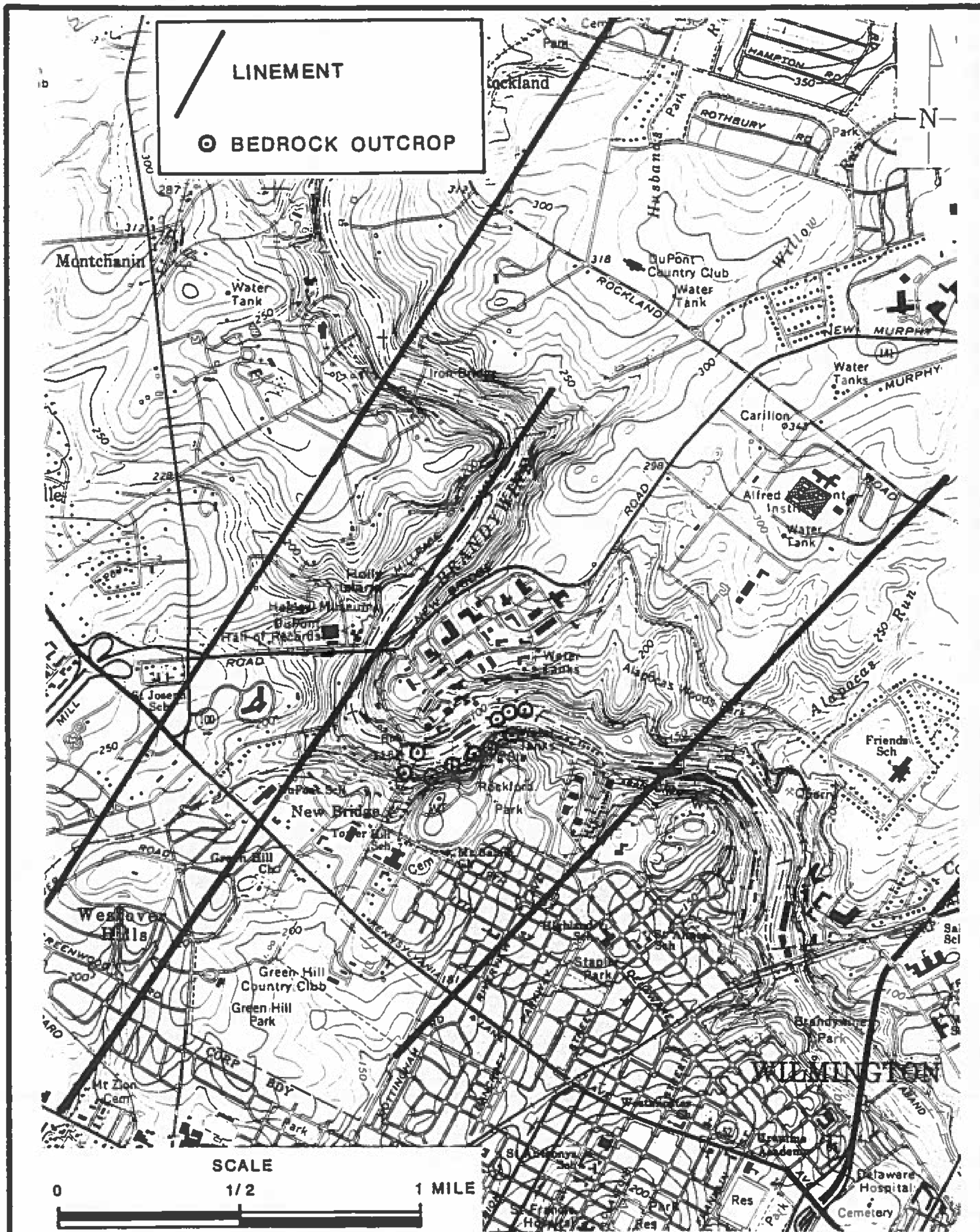

Figure 4.1. Linements in the vicinity of the DuPont Experimental Station.

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4.1.4 <u>Local Structural Survey</u>

A structural analysis of the fracture patterns in bedrock outcrops along the section of the Brandywine Creek south of the Experimental Station was completed for the RFI. Field mapping was performed (using a Brunton Compass) on rocks cropping out on both the north and the south side of the creek in publicly accessible areas (Figure 4.1).

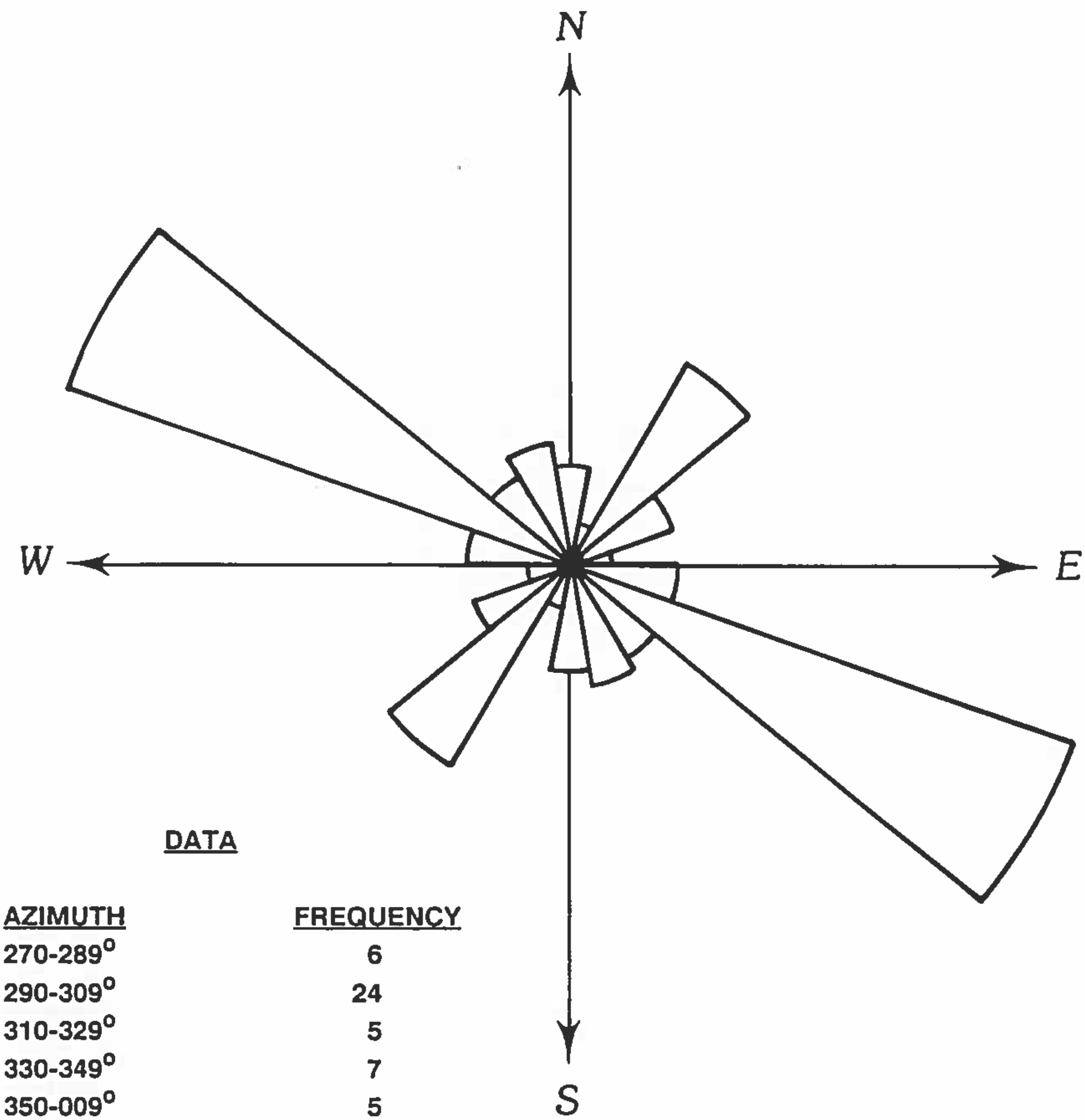
Numerous outcrops of hornblende-plagioclase gneiss (Woodruff and Thompson, 1975) were examined. Most of the outcrops were only 10 feet in width. Many smaller blocks of rock were exposed but did not appear to be in place and, therefore, were not examined. The strike and dip of a total of 70 rock surfaces were measured.

Most of the rock features measured are interpreted as joints. The joints are nearly all vertical in dip. Joint spacing is typically observed at one-meter intervals but also ranges up to three meters. Joint azimuths have been grouped into 20° increments and are plotted in a Rose Diagram (Figure 4.2). The dominant joint sets recognized are centered at 300° and 40°. The 300° joint set is nearly parallel to stream segments of the Brandywine Creek immediately upstream and downstream of the outcrop stations as well as the stream segment immediately upstream of the Brandywine/Hagley lineament. The 40° joint set is nearly parallel to the Brandywine/Hagley lineament.

The joint set parallel to the azimuth of the Brandywine/Hagley Lineament (20-40°) is not as prevalent as that observed in the rocks cropping out along the Brandywine Creek immediately west of the Experimental Station (Dressel, 1989). However, most of the outcrops along the section of the Brandywine immediately south of the Experimental Station generally are not well exposed in three dimensions and, therefore, this joint set is not easily recognized. It is likely, based on other work (Dressel, 1989), that the northeast-trending joints observed in the vicinity of the Brandywine/Hagley Lineament do exist in bedrock underlying the Experimental Station.

4.1.5 <u>Summary of Results</u>

The rocks at the DuPont Experimental Station typically reflect the regional geologic structure and contain two major near-vertical



DATA

AZIMUTH	FREQUENCY
270-289°	6
290-309°	24
310-329°	5
330-349°	7
350-009°	5
010-029°	3
030-049°	14
050-069°	5
070-089°	1
	70

Figure 4.2. Rose diagrams of measured joint azimuths.

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joint sets, centered at 300° and 40°, respectively. The joint spacing is highly variable and irregular, and joints are typically spaced one meter (3.3 ft) apart. It appears that the joints are the predominant fracture type in these rocks, as there is little evidence for faulting or other non-joint fractures (although some horizontal fractures probably exist). Therefore, groundwater flow is presumably controlled primarily by the orientation of the joints, and secondarily by the orientation of other fractures.

There is little or no evidence for the presence of extensive vertical or near-vertical zones at the site. Although there is wide-scale jointing, no specific areas inferred to be zones of densely shattered or fractured rock were identified. Consequently, no specific location appeared to be better than another for the placement of wells.

4.2 MONITOR WELL INSTALLATION

4.2.1 Well Locations

Ten new monitor wells were installed in the area of investigation to supplement four existing wells as stations for the collection of hydrogeologic data. Under the approved RFI workplan, three of the new wells were to be deep companion wells installed adjacent to existing wells (MW-2A, MW-3A, MW-4A). Additionally, three new well pairs (six wells) were to be installed in southwestern portion of the area of investigation (also known as Area 2). Subsequent to the workplan, DuPont proposed that an additional deep well be installed near existing well MW-1 to better define the three-dimensional aspects of groundwater flow.

The locations and specifications of proposed wells were modified after the installation of two deep wells (adjacent to MW-1A and MW-2A) failed to produce significant yield. After discussions with Mr. Tom Buntin and Mr. Robert Stroud of U.S. EPA, it was agreed that the new wells should be designed to evaluate the shallow bedrock system because the deeper system was demonstrated to be relatively impermeable. Therefore, the locations for the six new wells to be installed as pairs and the proposed companion well for existing well MW-4A were modified to provide a network of single shallow bedrock wells.

The final locations of the new wells, as well as the locations of existing wells, are shown in Figure 4.3. The change in locations allows better areal coverage of the area of investigation. Additionally, more data collection stations are available to monitor the principal groundwater discharge area (Brandywine Creek).

4.2.2 Well Installation Procedures

Two types of well specifications were used to install the new monitor wells. Wells in competent rock were completed as open boreholes. Borings that showed collapse during drilling were completed with screen and riser pipe. The two types of well construction are shown in Figure 4.4. All borings were installed by Walton Corporation (Newark, Delaware) using air rotary methods.

In general, installation procedures were as follows:

- Ten-inch diameter hole was drilled to a depth of 5-10 ft for shallow wells and 25-30 ft for deep wells.
- Eight-inch PVC casing was grouted in place to case off upper surface zones and prevent potential cross-contamination. For deep wells MW-1B and MW-2B, six-inch steel casing was used.
- If the borehole was competent, the well was completed as a six- or eight-inch diameter open borehole.
- If the borehole was not competent, a six-inch temporary casing was installed to the desired well depth. Four-inch PVC screen (10 slot) and riser pipe were placed in the temporary casing. A clean sand filter pack was installed around the screen as the temporary casing was withdrawn. The sand pack was placed to approximately one foot above the screen. The remainder of the annulus was filled with bentonite and grout to provide a surface seal.
- All wells were completed flush with land surface and with locking caps.

The pertinent data associated with well installation are provided in Appendix C and are summarized in Table 4.1. Table 4.1 includes the

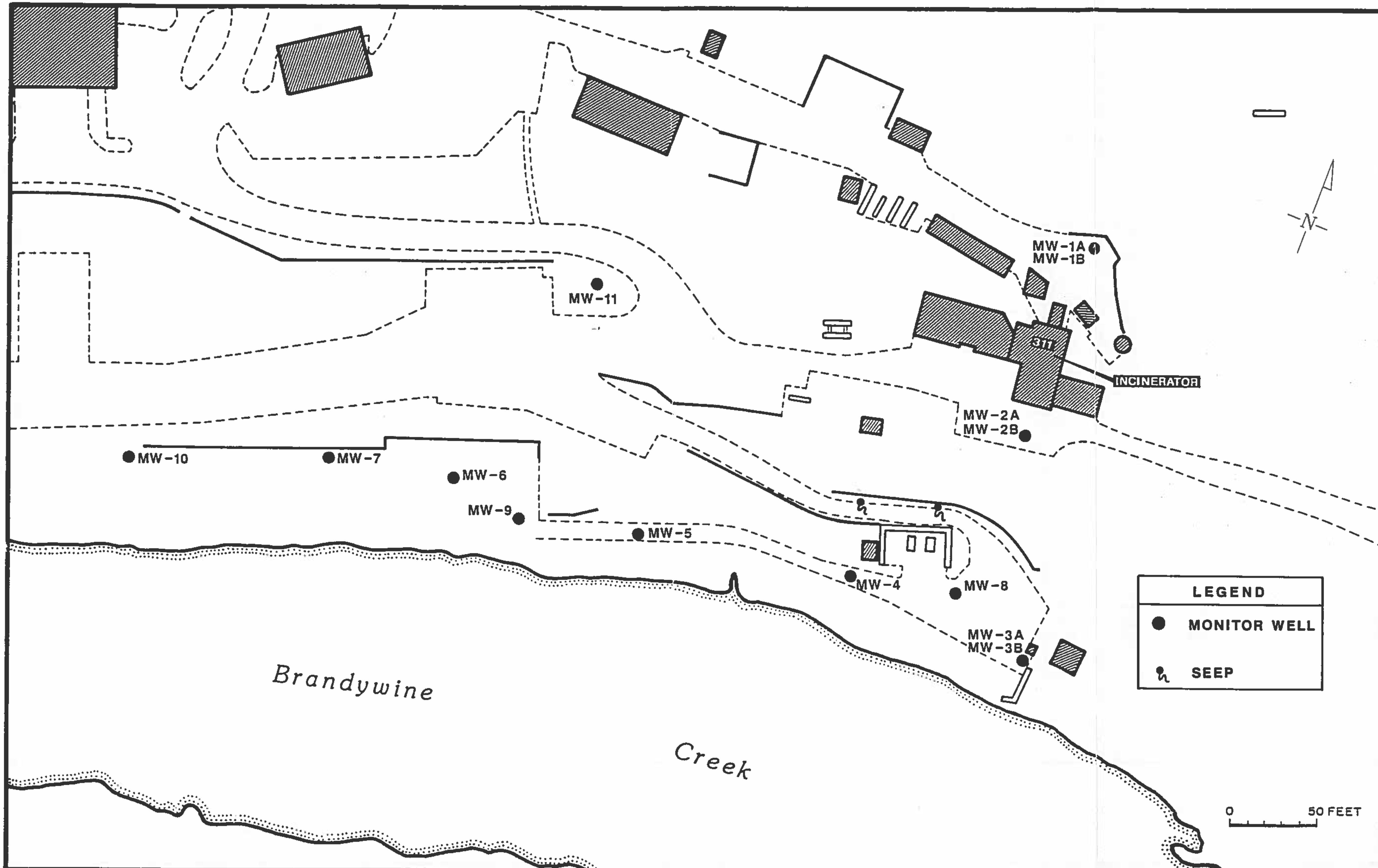

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Figure 4.3. Location of monitor wells and groundwater seeps.

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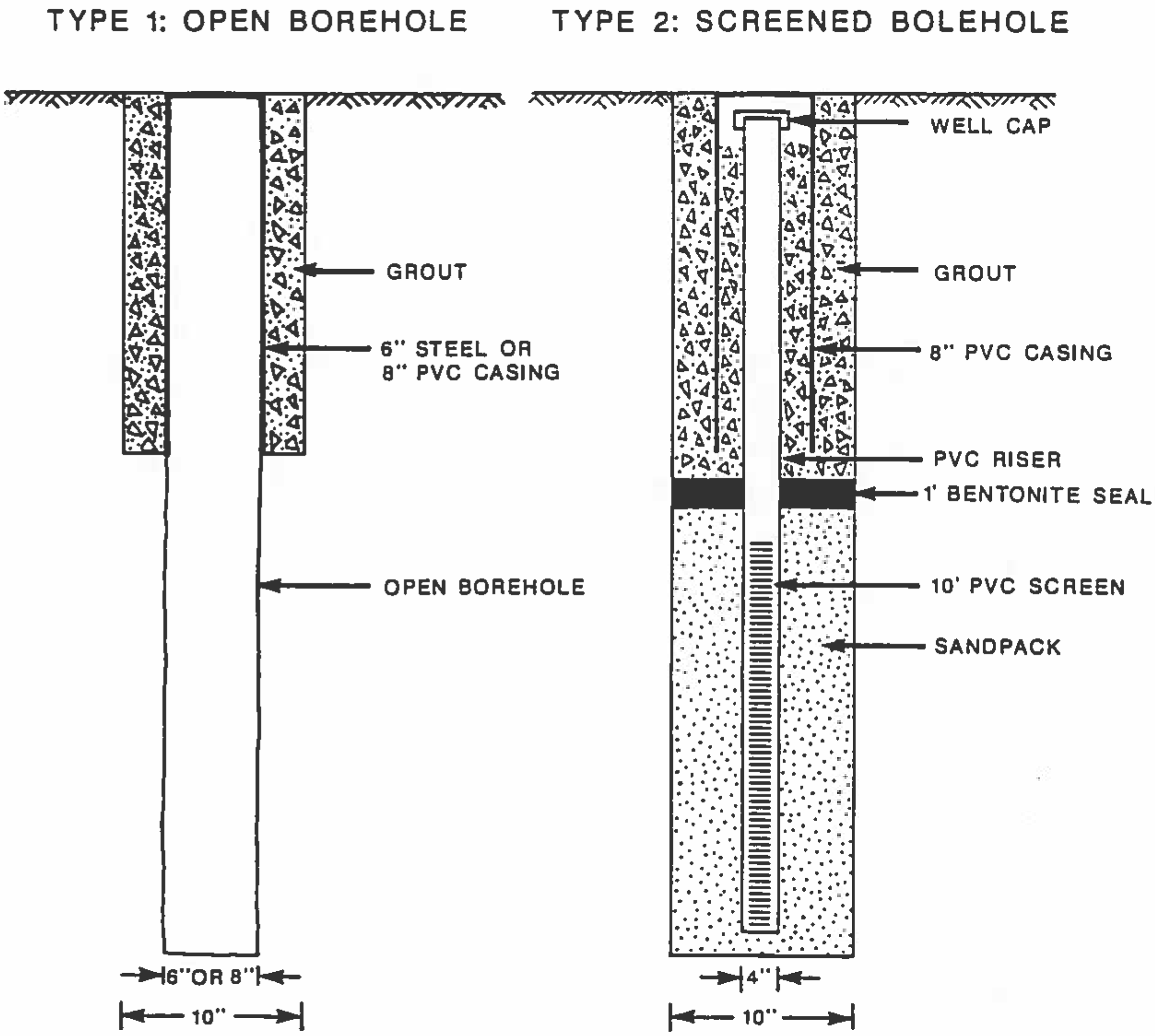

Figure 4.4. New monitor well construction specifications.

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Table 4.1. Monitor well installation data.

Well No.	Date Completed	Total Depth (ft)	Open Interval (ft-ft)	Well Diameter (in)	Screened
MW-1A	10-86	38.6	19.2-38.6	6	No
MW-1B	12-15-89	102	42-102	6	No
MW-2A	10-86	22*	20.1-40	6	No
MW-2B	12-12-89	81.3	42-81.3	6	No
MW-3A	10-86	20.1	5.1-20.1	4	Yes
MW-3B	12-18-89	38.5	26.3-38.5	4	Yes
MW-4	10-86	20.6	12.5-20.6	6	No
MW-5	12-14-89	20	8-20	8	No
MW-6	12-19-89	20	8-20	6	No
MW-7	12-21-89	40	11-40	6	No
MW-8	12-20-89	20	8-19.4	4	Yes
MW-9	12-21-89	20	8-19	4	Yes
MW-10	12-20-89	41.7	9.1-41.7	6	No
MW-11	12-15-89	20	7.9-20	4	Yes

*Original depth of well was 40 ft. Well was grouted in during installation of well MW-2B. New well depth is 22 ft.

information for the four existing wells obtained from previous well completion reports filed by Walton.

The geology was logged from cuttings examined by a geologist during drilling. The geologic log for each borehole is provided in Appendix C. The rocks underlying the site are consistent with the regional geology discussed in Section 4.1. The overburden overlying the gneiss bedrock consists of brown, silty sand and cobbles (fill) and brown rock fragments (weathering product of the gneiss).

No visual signs of contamination were recorded during drilling. Air monitoring with the Photovac Microtip was performed throughout well installation. At MW-2B, the instrument measured 37 ppm calibrant gas equivalent (CGE) above background at the top of the borehole (borehole depth was 24 ft). No other readings above background were observed at this or any other borehole.

After completion of all wells, vertical control data, including land surface and top of casing elevations, were surveyed. These elevations are provided in Table 4.2. The supporting survey data are provided in Appendix C.

4.3 BOREHOLE SURVEYS

4.3.1 Video Borehole Survey

A video survey of each open-hole well was performed to directly observe fracture patterns across the open interval. Additionally, well construction information was checked. The survey was conducted by Nittany Geoscience, Inc. (State College, PA). The video system used was developed by Marks Products, Inc., of State College, PA. The camera is a Geovision™ high-resolution, low-light, black-and-white, solid state video camera with a 4.5-mm, wide-angle, auto-iris lens mounted in a stainless-steel, water-proof housing. The camera is lowered by a hand-operated winch, mounted on an adjustable tripod, with 500 feet of coaxial cable and a mechanical footage counter. The video cassette is recorded on a Magnavox VCR. Downhole progress is monitored throughout the survey on a 4.5-inch black and white TV monitor. The depths of visible features are noted verbally with a microphone.

Table 4.2. Vertical control data for monitor wells.

Well No.	Elevation (ft above mean sea level) Land Surface	Outer Casing Rim	Inner Casing Rim
MW-1A	141.61	143.59	NA
MW-1B	141.74	141.77	141.43
MW-2A	181.12	120.03	NA
MW-2B	118.09	118.26	117.95
MW-3A	83.91	85.89	85.59
MW-3B	82.71	82.78	82.57
MW-4	82.62	84.46	NA
MW-5	81.01	81.05	80.59
MW-6	82.34	82.38	81.89
MW-7	82.49	82.57	81.89
MW-8	81.86	81.88	81.23
MW-9	81.44	81.41	80.84
MW-10	82.52	82.57	82.02
MW-11	111.97	111.94	111.56

Benchmark (aluminum disk on concrete mound) = 110.34 ft above MSL
NA = No inner casing

Camera accessories include a compass, side-look mirror with light deflector, and a light projector.

First, the tripod and winch were set up and the camera was attached to the coaxial cable and centered in the casing. The camera was then set at ground level and the footage counter initialized at zero. The recording system and camera were turned on and the camera was lowered into the hole. Verbal comments were recorded at the appropriate locations.

The wells were logged from 8:00 am to 5:00 pm on January 16, 1990, in the following order: MW-10, MW-7, MW-6, MW-5, MW-4A, MW-1B, MW-1A, MW-2B, and MW-2A. The water in MW-4A was cloudy. The light projector was used to project the light 6.5 inches in front of the camera, thus reducing the back-scatter directly in from of the lens. This did not improve the image, so the light projector was removed and the side-look mirror was installed. This clarified the picture and enabled the geologist to determine the location of the various features with greater ease.

As the camera was removed from the borehole the cable was rinsed with deionized water and wiped dry with paper towels. The camera was scrubbed in an Alconox solution and rinsed with deionized water. Spent cleaning solution was contained in a 20 gallon basin and disposed at the decontamination pad at the end of the day.

The video cassette was returned to the office of Nittany Geoscience, Inc., and reviewed. Features, their depths and orientations were then tabulated. This information is presented in Table 4.3. Several fracture zones are identified in each borehole. A schematic representation of the video log is shown for each surveyed well in Plate 4 and Figures 4.5 through 4.16.

4.3.2 Downhole Geophysical Survey

Borehole geophysical surveys were conducted in both new and pre-existing wells. The surveys were conducted by Appalachian Coal Surveys (Apollo, PA).

Two suites of parameters were run in all wells. A lithology log (including caliper, gamma, and electric) were performed to measure

Table 4.3. Structural and hydrologic features in video-surveyed wells, DuPont Experimental Station, Wilmington, DE.

Well Number	Depth (ft)	Feature	Orientation
MW-1B	42	bottom of casing	
	55	joints/fracture zone	N/S
	56	joints/fracture zone	E/W
	59	fracture zone	
	60	joints	N/S
	66	vertical fracture	
	68	vertical fracture	
	70	vertical fracture	
	74	discontinuity	
	76	joints	
	77 - 79	fracture zone	
	80	joints	
	89	joints	
	92.5	joints	
	95.5	water level	
	99.5	loss of visibility	
	100	bottom of hole	
MW-1A	20	bottom of casing, fracture zone	
	29	fracture zone	
	33.5	water level	
	39	bottom of hole	
MW-2B	42	bottom of casing	
	43	fracture zone	
	45	fracture zone	
	52	fracture zone	NE/SW
	55	fracture zone	
	62	fracture	
	67	fracture/joint	
	70	fracture zone	
	71.5 - 72	fracture zone	
	73.5	discontinuity/ fracture zone	
	78.5	water level	
	79	fracture zone	
	80	small fracture zone	
	81	bottom of hole	
MW-2A	19.5	bottom of casing	
	19.5 - 20	fracture zone	E/W
	21	fracture	
	22	bottom of hole	

Table 4.3. (Continued)

Well Number	Depth (ft)	Feature	Orientation
NW-10	9	bottom of casing	
	10	fracture	
	15	fracture	
	17	fracture	
	40	water level, fracture zone	
	41	bottom of hole	
	20	joint	N/S
	16	joint	N/S
MW-7	10	bottom of casing	
	15	compositional or structural discontinuity	
	30	water level	
	31	joint	E/W
	35 - 35	fracture zone	E/W
	37	discontinuity	E/W
	40	bottom of hole	
	23	joint/discontinuity	
	13 - 14	fracture	NE/SW
MW-6	6	water level	
	8	bottom of casing	
	13 - 14	fracture zone	E/W
	16, 18	joints	N/S
	20	bottom of hole	
MW-5	6.5	water level	
	8	bottom of casing	
	8 - 9	fracture zone	
	12 - 13	fracture zone	NNW
MW-4A	11	water level	
	12	bottom of casing	
	12.5	fracture zone	
	14.5	fracture zone	
	15 - 17.5	fracture zone	
	20	bottom of hole	

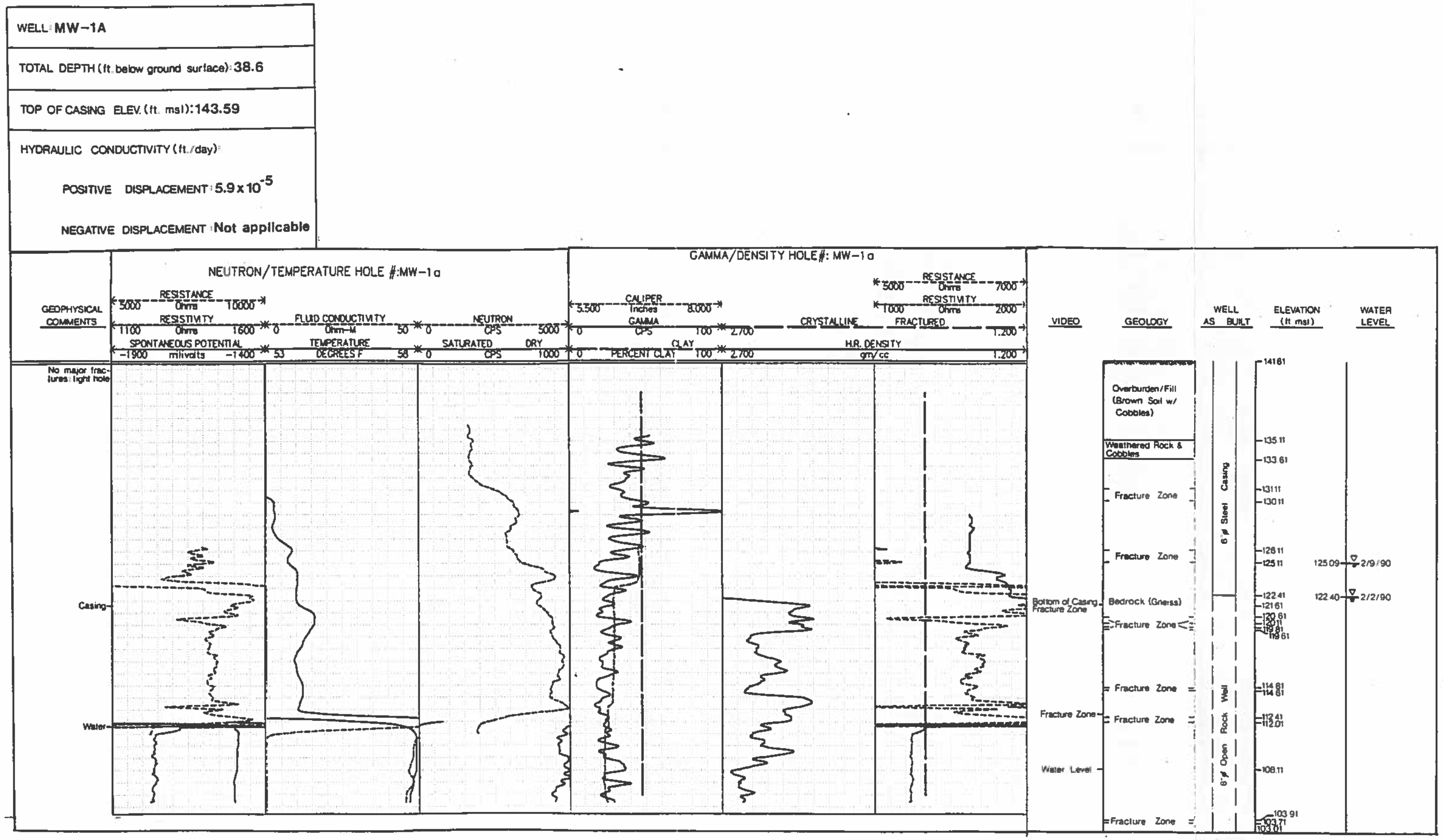

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Figure 4.5. Summary of geologic information collected at monitor well MW-1A.

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WELL: MW-2A

TOTAL DEPTH (ft. below ground surface): 40.0

TOP OF CASING ELEV. (ft. msl): 120.03

HYDRAULIC CONDUCTIVITY (ft./day):

POSITIVE DISPLACEMENT: 10.66

NEGATIVE DISPLACEMENT: Not applicable

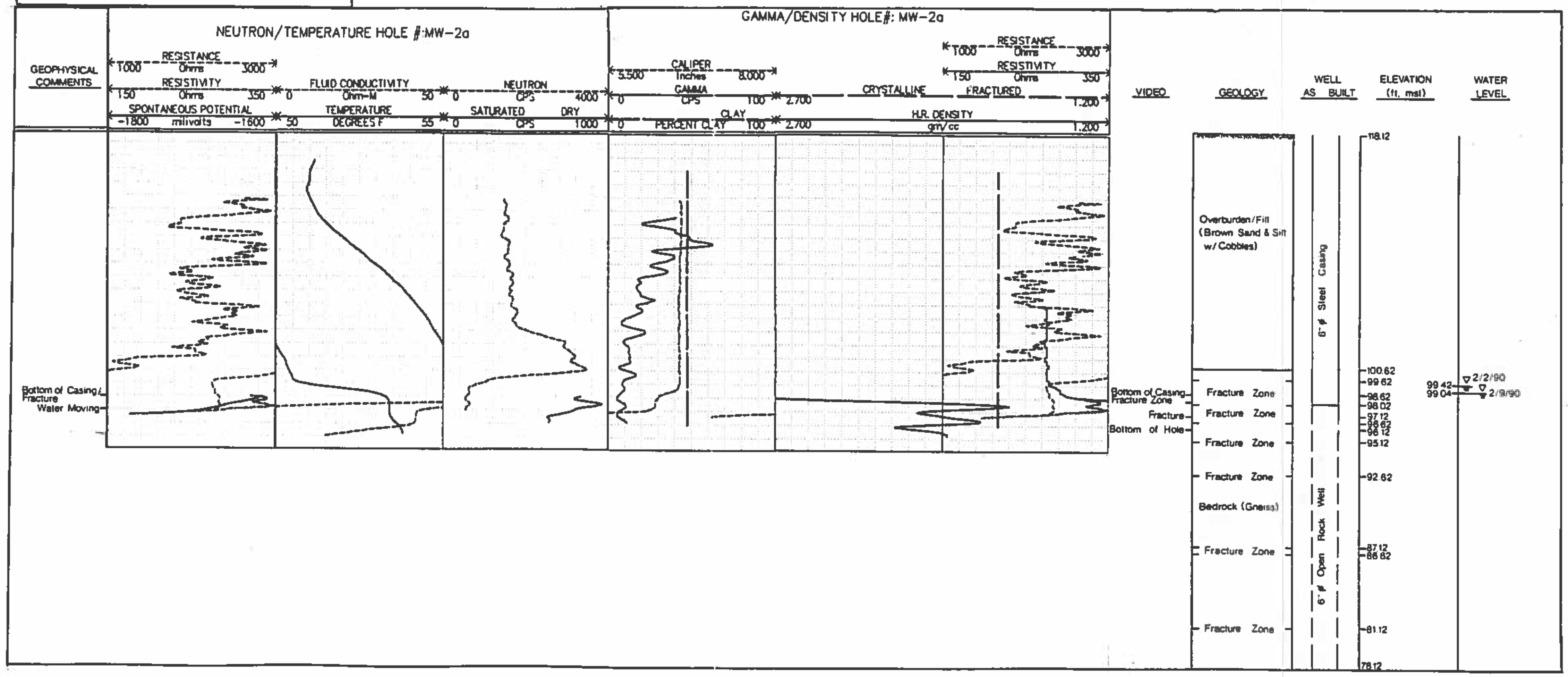

Figure 4.6. Summary of geologic information collected at monitor well MW-2A.

WELL: MW-3A

TOTAL DEPTH (ft. below ground surface): 20.1

TOP OF CASING ELEV. (ft. msl): 85.59

HYDRAULIC CONDUCTIVITY (ft./day):

POSITIVE DISPLACEMENT: 0.71

NEGATIVE DISPLACEMENT: 0.14

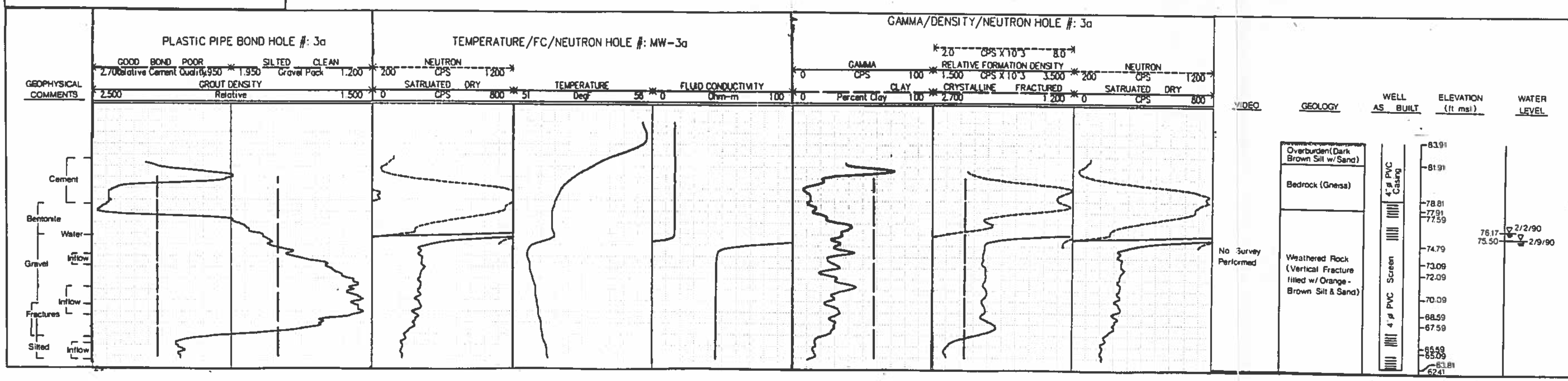

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Figure 4.7. Summary of geologic information collected at monitor well MW-3A.

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WELL: MW-3B

TOTAL DEPTH (ft. below ground surface): 40.0

TOP OF CASING ELEV. (ft. msl): 82.57

HYDRAULIC CONDUCTIVITY (ft./day):

POSITIVE DISPLACEMENT: 0.21

NEGATIVE DISPLACEMENT: Not applicable

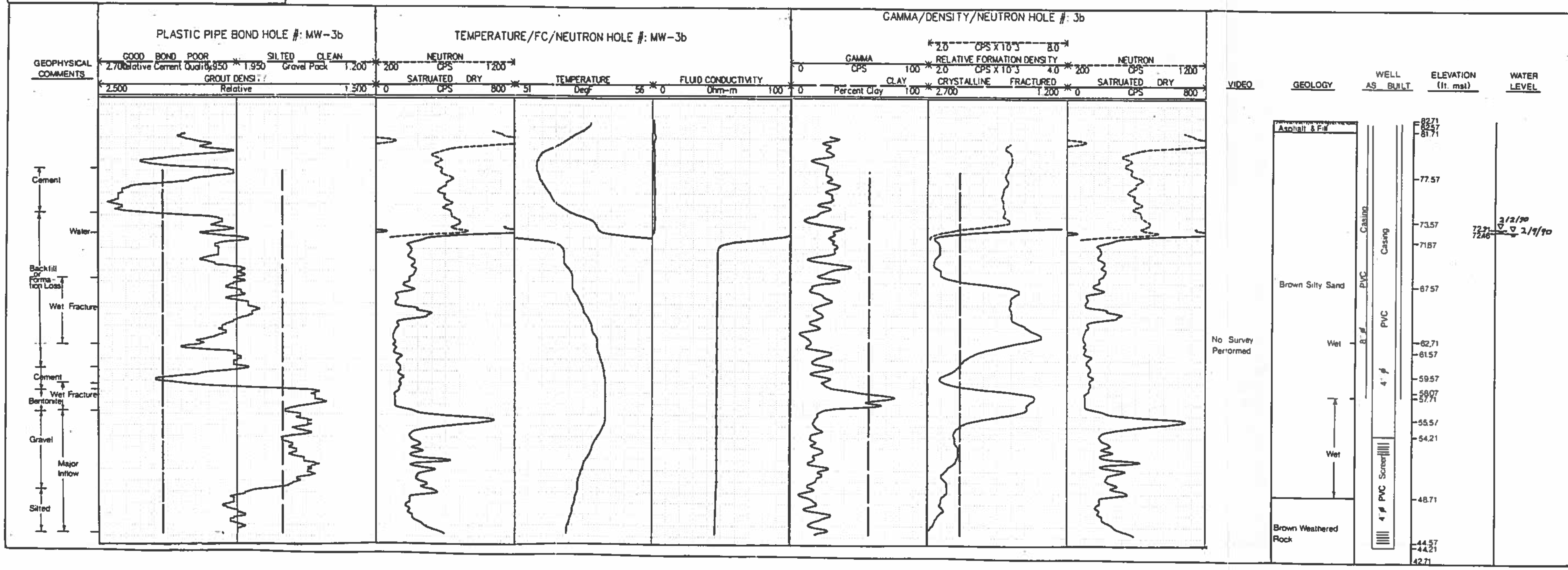

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Figure 4.8. Summary of geologic information collected at monitor well MW-3B.

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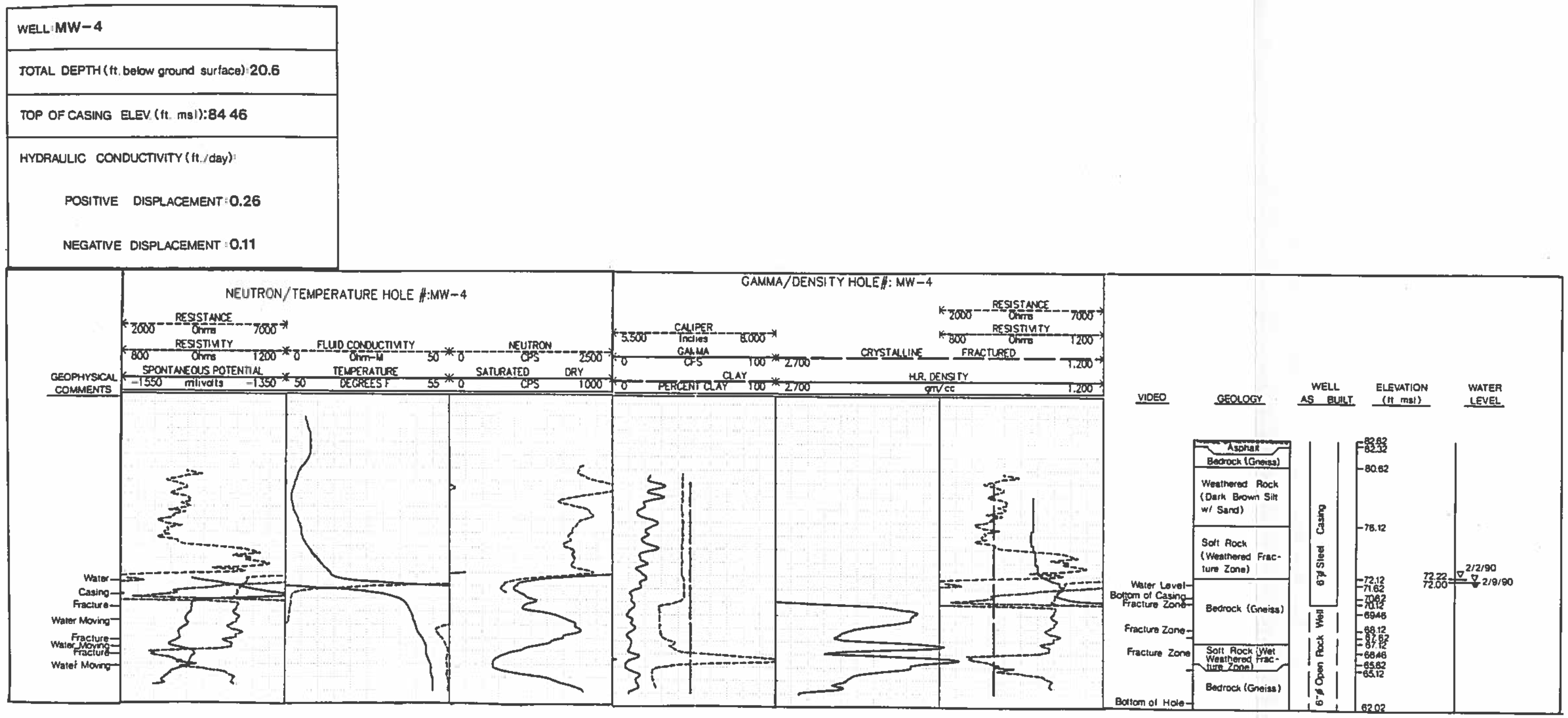

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Figure 4.9. Summary of geologic information collected at monitor well MW-4.

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WELL: MW-5

TOTAL DEPTH (ft. below ground surface): 20.0

TOP OF CASING ELEV. (ft. msl): 80.59

HYDRAULIC CONDUCTIVITY (ft./day):

POSITIVE DISPLACEMENT: 9.20

NEGATIVE DISPLACEMENT: 3.29

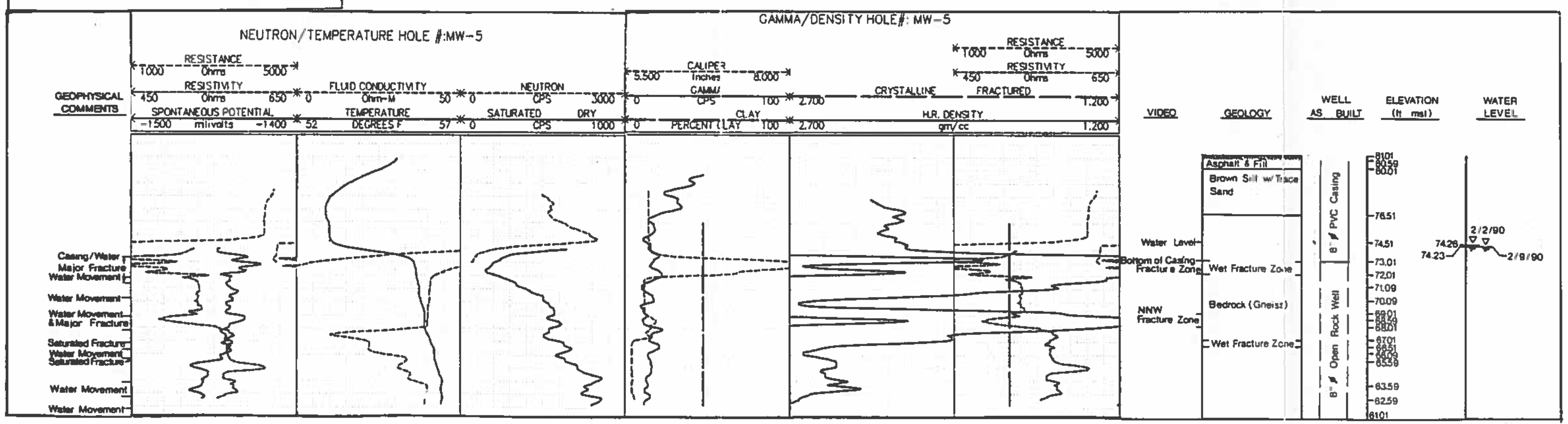

Figure 4.10. Summary of geologic information collected at monitor well MW-5.

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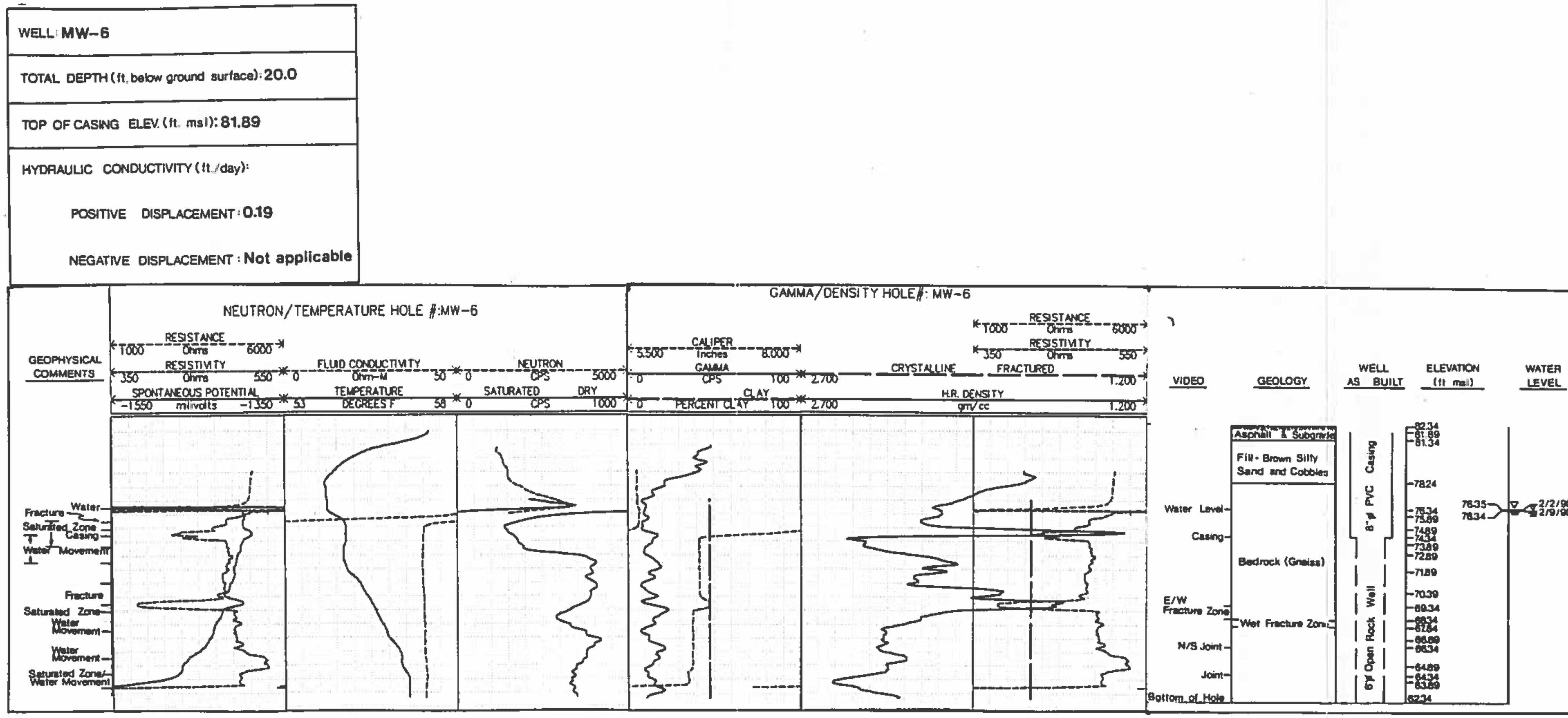

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Figure 4.11. Summary of geologic information collected at monitor well MW-6.

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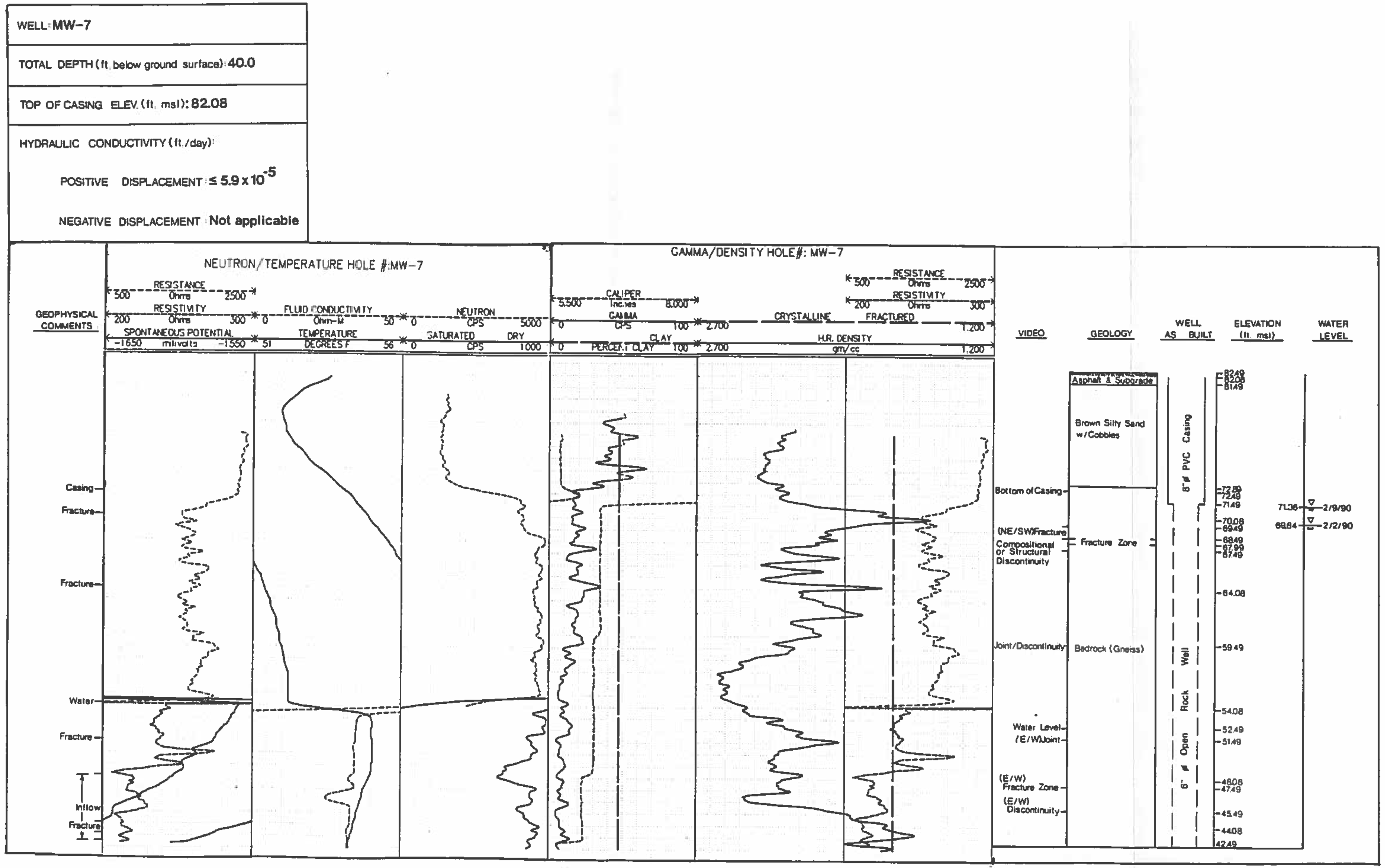

Figure 4.12. Summary of geologic information collected at monitor well MW-7.

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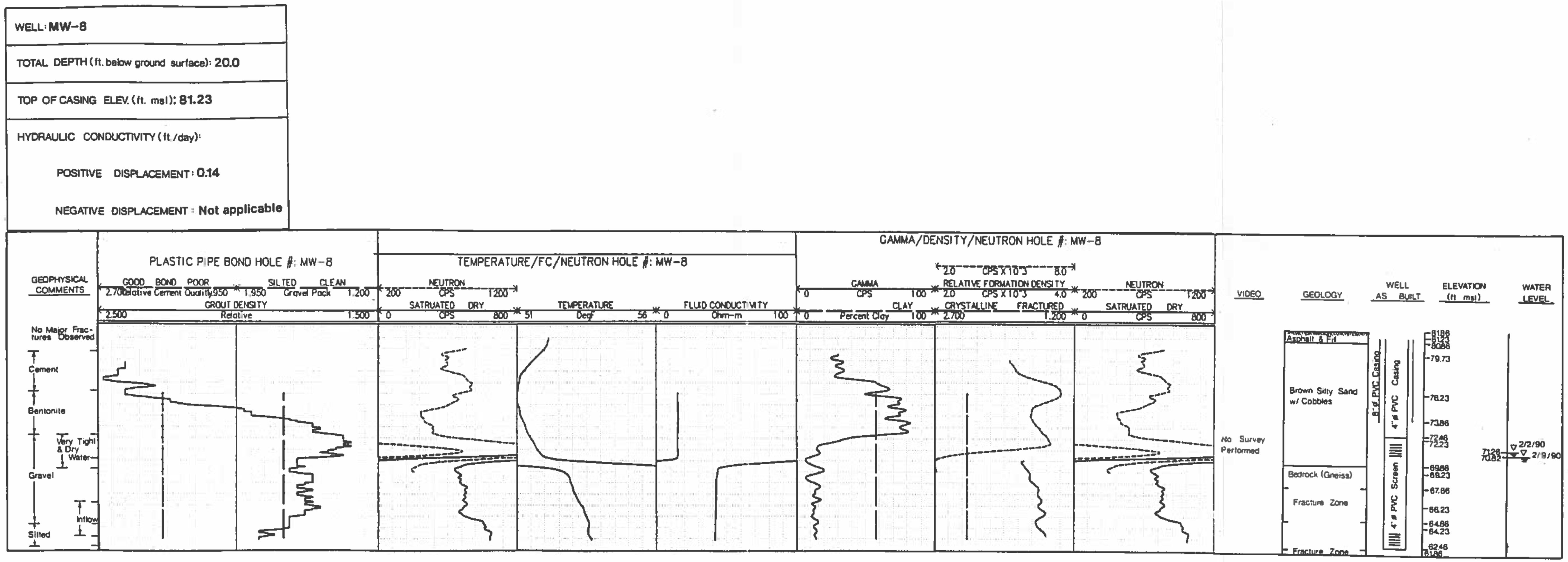

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Figure 4.13. Summary of geologic information collected at monitor well MW-8.

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WELL: MW-9

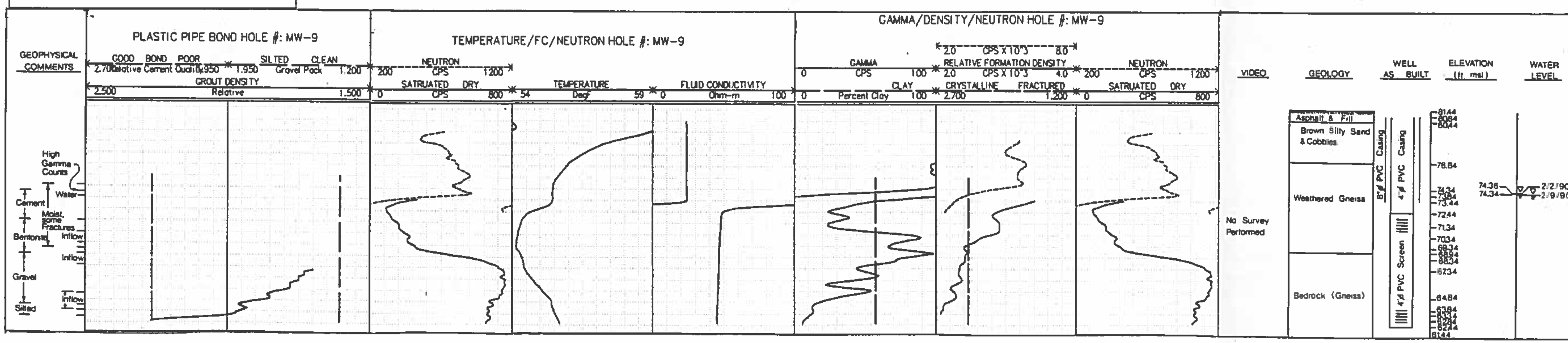
TOTAL DEPTH (ft. below ground surface): 20.0

TOP OF CASING ELEV. (ft. msl): 80.84

HYDRAULIC CONDUCTIVITY (ft./day):

POSITIVE DISPLACEMENT: 16.90

NEGATIVE DISPLACEMENT: Not applicable



GeoTrans / Tetra Tech   Figure 4.14. Summary of geologic information collected at monitor well MW-9.

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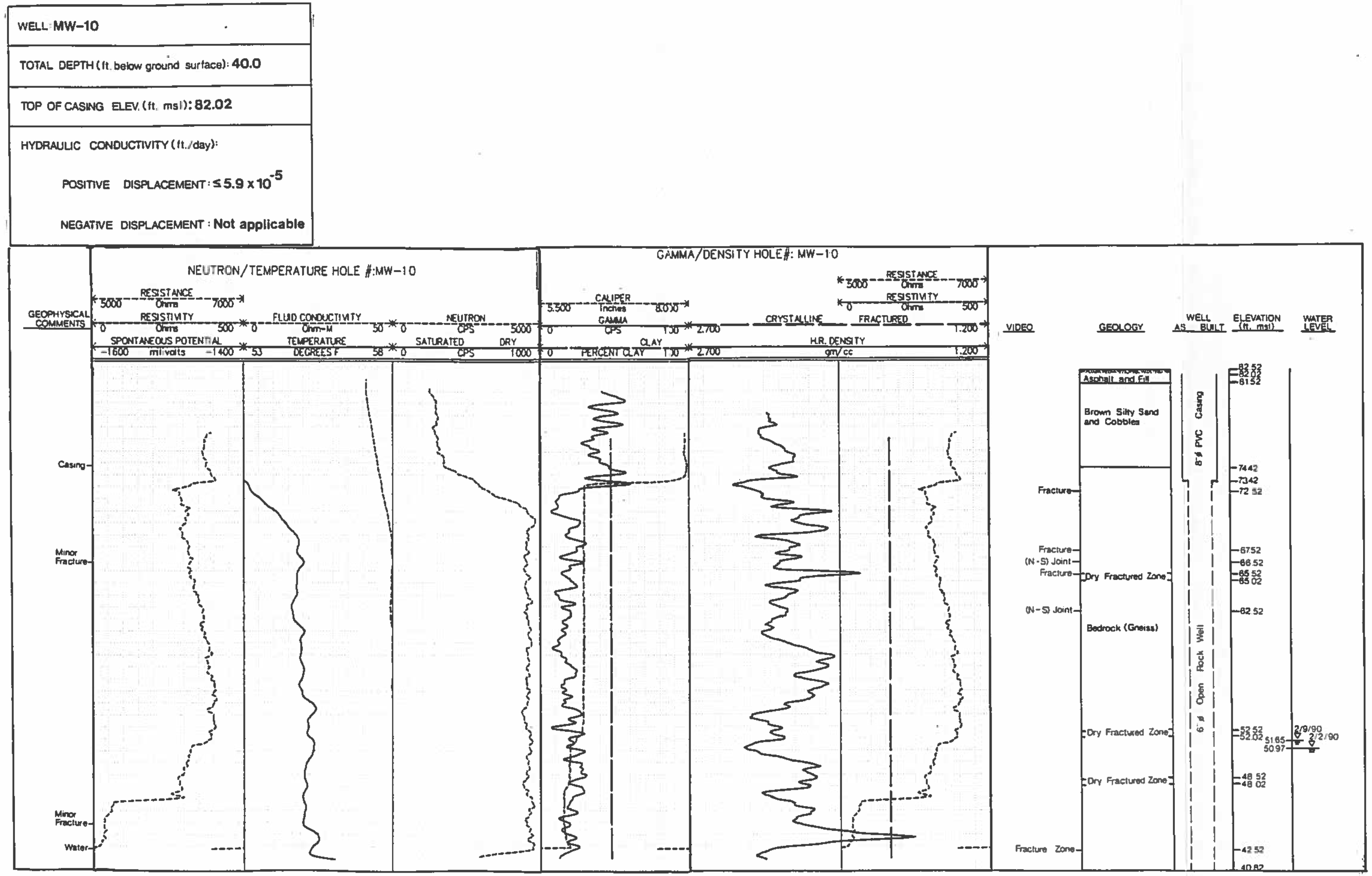

Figure 4.15. Summary of geologic information collected at monitor well MW-10.

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WELL: MW-11

TOTAL DEPTH (ft. below ground surface): 20.0

TOP OF CASING ELEV. (ft. msl): 111.56

HYDRAULIC CONDUCTIVITY (ft./day):

POSITIVE DISPLACEMENT: 0.91

NEGATIVE DISPLACEMENT: Not applicable

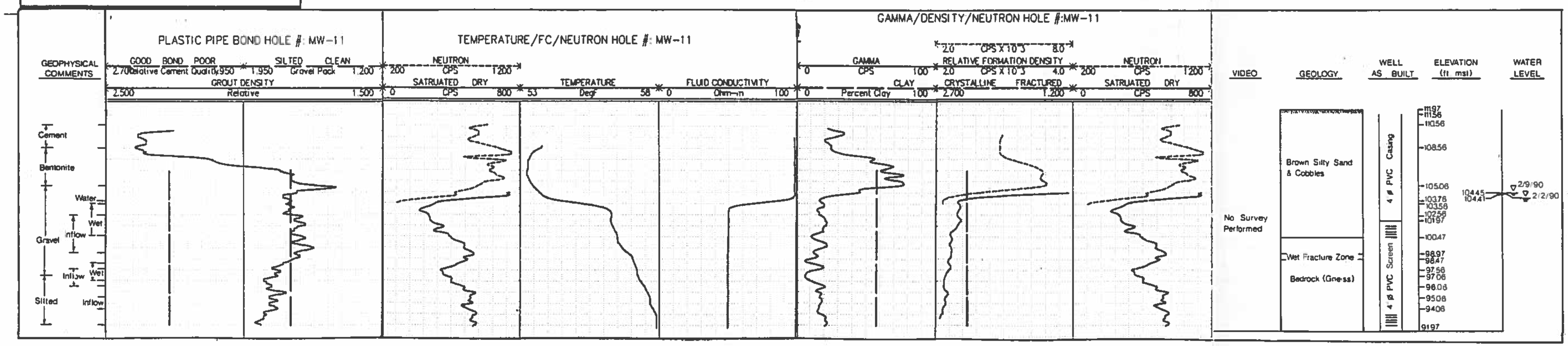

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Figure 4.16. Summary of geologic information collected at monitor well MW-11.

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borehole diameter, identify fracture zones, and identify changes in lithology. Temperature, fluid conductivity, and neutron runs were performed to identify groundwater inflow/outflow zones. Additionally, grout density logs were run in wells that are screened over the open interval. These logs identify occurrence of well construction materials such as grout, bentonite, gravel in the annulus.

The logs are compiled with other well information in Plate 4 and Figures 4.5 through 4.16. Features identified from the survey results are described to the left of the logs. In two cases (MW-3A and MW-9), the grout density logs indicated the presence of clay below the top of the screen. This was interpreted as part of the bentonite layer. Well MW-3A was constructed prior to this investigation, however during well installation of MW-9, the geologist measured the depth to the gravel pack with a weighted tape to ensure that gravel was placed at least one foot above the screen. The presence of clay below the screen indicates that some of the grout may have infiltrated the gravel pack. As a result, the permeability of the screen may be slightly reduced.

4.4 AQUIFER TESTING

4.4.1 Slug Tests

4.4.1.1 Data Collection Procedures

Slug tests were conducted at the DuPont Experimental Station site in two episodes. The four existing wells were tested on December 11-12, 1989 and the ten new wells were tested on January 9-11, 1990.

A slug test is performed by creating an instantaneous water-level change within the well and measuring the rate at which the displaced water level returns to the pre-test level. The water-level change can be accomplished by either injecting into the well or withdrawing from the well a volume of water or a weighted float. The rate of water-level recovery can then be related to the hydraulic conductivity of the surrounding aquifer material.

In tests conducted at the DuPont site, the use of injection or withdrawal techniques depended on the height of the water column in the well. In the case of injection, an approximate 3-gallon slug of distilled water was placed into the well via a plastic container that well. In the case of injection, an approximate 3-gallon slug of distilled water was placed into the well via a plastic container that was modified to allow fast drainage. Alternatively, a weighted float, either 4-inch diameter or 3-inch diameter PVC cylinder, depending on the well diameter, was used to affect the desired displacement.

The depth-time relationship resulting from the injected slug/cylinder was recorded using a TERRA 8/D data logger and an accompanying 5 psi transducer. The transducer has an accuracy of ±0.01 feet and the recorder has a minimum logging interval of one second. The recorder was configured such that the data logger readings were written both to the recorder's RAM memory and directly to the display of an attached portable PC, thus allowing for real-time monitoring of the test as it progressed. The PVC cylinders, the transducer, and associated cable were cleaned with distilled water and a nonphosphate, low-sudsing detergent prior to each test. Pre-test water levels were measured with a QED electric water-level probe.

During the first episode, existing wells were tested in order of increasing contamination based on available data. These slug tests were conducted in the following order: MW-3A, MW-4A, MW-1A, and MW-2A. In the second episode, tests were conducted in the following order: MW-6, MW-9, MW-7, MW-3B, MW-10, MW-5, MW-8, MW-1B, MW-2B, and MW-11. The date of each test and the test method used are shown in Table 4.4. The PVC cylinders were used to effect the desired water-level displacement for all wells except MW-2A, MW-2B, and MW-10. The cylinder could not be used in wells MW-2A and MW-10 due to a small water column height (3.94 feet and 2.92 feet, respectively) and these wells were tested using an injected volume of distilled water (approximately 3-gallons). The same method was selected for MW-2B, although either method could have been used.

Duplicate (i.e., both positive and negative displacement) tests were conducted in wells MW-3A, MW-4, and MW-5 as a check on results. The response curves and associated data from all slug tests conducted for the RFI are provided in Appendix D.

Table 4.4. Date of slug tests and test method used.

Well	Date Tested	Method	Comments
1A	12-12-89	PVC slug rod with transducer	Very slight response.
1B	01-11-90	PVC slug rod with transducer	No response.
2A	12-12-89	H_2O slug with transducer	Pre-test level not at equilibrium.
2B	01-11-90	H_2O slug with hand-held meter	No response, used water slug due to time constraints.
3A	12-11-89	PVC slug rod with transducer	
3B	01-10-90	PVC slug rod with transducer	
4	12-11-89	PVC slug rod with transducer and hand-held meter	
5	01-10-90	PVC slug rod with hand-held meter for positive test and transducer for negative test	
6	01-09-90	PVC slug rod, data collected by hand-held meter	Terra 8 recorder not in service for test.
7	01-10-90	PVC slug rod with transducer	Very slight response.
8	01-10-90	PVC slug rod with transducer	
9	01-09-90	PVC slug rod with transducer	
10	01-10-90	Distilled H_2O with hand-held meter	Pre-test level not at equilibrium. Very slight response.
11	01-11-90	PVC slug rod with transducer	

4.4.1.2 Results

The two methods used to analyze the slug test data are described in Bouwer and Rice (1976) and Cooper, et al. (1967). The theory and limitations of these methods are summarized in Appendix D.

The calculated hydraulic conductivity values (Table 4.5) range from 5.9 x 10^{-5} ft/day (MW-1A) to 16.9 ft/day (MW-9). There is a noticeable difference in the hydraulic conductivity magnitude calculated for the positive and negative displacement tests conducted in wells MW-3A, MW-4, and MW-5. The positive displacement hydraulic conductivity values are greater in magnitude than the negative displacement values. This is most likely caused by the presence of unsaturated fractures above the static water level. When the water level is positively displaced, the fractures afford additional flow paths. A slug test is generally intended to provide only "order of magnitude" estimates of hydraulic conductivity, therefore, the differences between the positive and negative displacement hydraulic conductivity values are not considered significant.

The small water column in well MW-2A and MW-10 suggest that pre-test levels in these wells were not at equilibrium with the formation. Therefore, the test results are considered suspect. High hydraulic conductivity values in MW-5 and MW-9 probably reflect the presence of water-bearing fractures.

4.4.2 Injection Tests

4.4.2.1 Procedure

Injection tests were conducted between March 10 and 13, 1990 to evaluate hydraulic properties in the vicinity of Wells MW-2A, MW-3A, MW-5, MW-9, and MW-11. During each test, clean water piped from a tanker truck was injected at a constant rate. Injection rates were monitored using a calibrated orifice weir and were adjusted as necessary using a gate valve. Water levels in the injection well and nearby observation wells were monitored during injection and recovery using pressure transducers and electric-line water-level probes.

Table 4.5. Results of slug tests.

Well	Method of Analysis	Hydraulic Conductivity (ft/d)	Saturated Thickness (ft)	Transmissivity (ft^2/d)
1A	Bouwer & Rice	$5.9x10^{-5}$	26.8	1.6x10-3
1B	--	NR	--	--
2A	Cooper, et al.	10.66	3.9	41.6
2B	--	NR	--	--
3A	Cooper, et al.	0.71	11.8	8.4
3A	Cooper, et al.[1]	0.14	11.8	1.7
3B	Cooper, et al.	0.21	28.3	5.9
4	Cooper, et al.	0.26	10.1	2.6
4	Cooper, et al.[1]	0.11	10.1	1.1
5	Cooper, et al.	9.20	13.9	127.9
5	Cooper, et al.[1]	3.29	13.9	45.7
6	Cooper, et al.	0.19	14.6	2.7
7	--	NR	--	--
8	Cooper, et al.	0.14	14.0	2.0
9	Bouwer and Rice	16.90	12.5	211.3
10	--	NR	--	--
11	Cooper et al.	0.91	13.1	11.9

[1] - Negative displacement test
NR - Insufficient response for analysis.

4.4.2.2 Results

A summary of the injection/recovery tests conducted at the site is given in Table 4.6. Hydraulic head changes caused by injection are graphed in Figures 4.17 to 4.21. Observed hydraulic head responses were limited to the injection wells, except for the test at Well MW-3A during which a hydraulic head response was seen 18 ft away at Well MW-3B. The tests were analyzed using the Theis time-drawdown equation (Reed, 1980), the Theis recovery method (Kruseman and DeRidder, 1976), and a least-squares best-fit analysis based on superposition of the Theis equation for the variable-rate injection tests at MW-9 and MW-11. Hydraulic property estimates derived from these tests are given in Table 4.7. As shown, transmissivity estimates derived from these tests range from 2.2 to 370 ft^2/d. A storage coefficient of 0.013 was estimated from build-up data at MW-3B during injection at MW-3A.

4.4.3 Dye Tracer Study

4.4.3.1 Procedure

A dye tracer study was performed at the site during the period March 19, 1990 to April 20, 1990, to evaluate hydrologic connections at the site. Dyes were used as tracers because of the following properties:

- Little or no toxicity that could pose a threat to human health or environment;
- Detectability in extremely small concentrations;
- Low cost of the dye and dye analysis.

Three different dyes were used at the site: Rhodamine WT, Fluorescein, and an optical brightener. Rhodamine WT was injected into well MW-2A, Fluorescein was injected into well MW-2B, and optical brightener was injected into well MW-11. Wells MW-3A, MW-3B, MW-8, MW-4, and two seeps were monitored for the Rhodamine WT and Fluorescein dyes, and wells MW-5, MW-6, MW-7, MW-9, and MW-10 were monitored for

Table 4.6. Summary of Injection Tests Conducted March 10-13, 1990 at the DuPont Experimental Station, Wilmington, Delaware.

Date	Injection Well	Injection History		Observation Wells*
		Military Time:	GPM (MINUTES)	
3/10/90	2A	1022-1622:	1.0 gpm (360)	All(2B)
3/11/90	11	0938-1038: 1038-1145: 1145-1638:	1.0 gpm (60) 0.0 gpm (67) 0.5 gpm (293)	All
3/12/90	9	0925-0932: 0932-1036: 1036-1101:	2.0 gpm (7) 0.0 gpm (64) 2.7 gpm (25)	4,5,(6),7,10
3/12/90	5	1310-1703:	1.0 gpm (233)	4,6,7,(9),10
3/13/90	3A	0815-1217:	1.0 gpm (242)	3B,4,5,(8),1A,1B

*The observation well monitored using a pressure transducer is shown in parentheses.

NOTE: "All" refers to Wells 1A, 1B, 2A, 2B, 3A, 3B, 4, 5, 6, 7, 8, 9, 10, and 11.

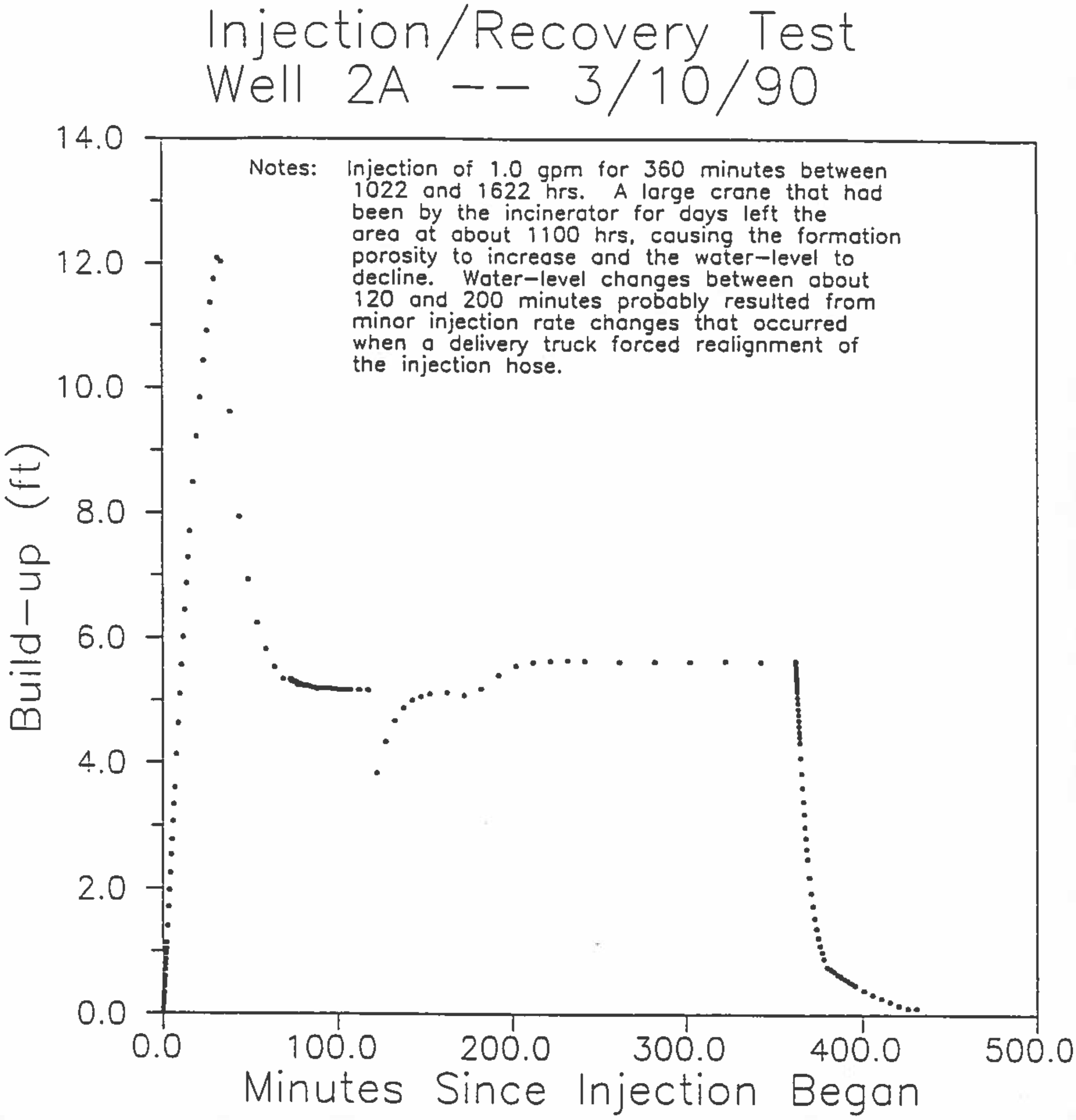

Figure 4.17a. Pumping test results at well MW-2A.

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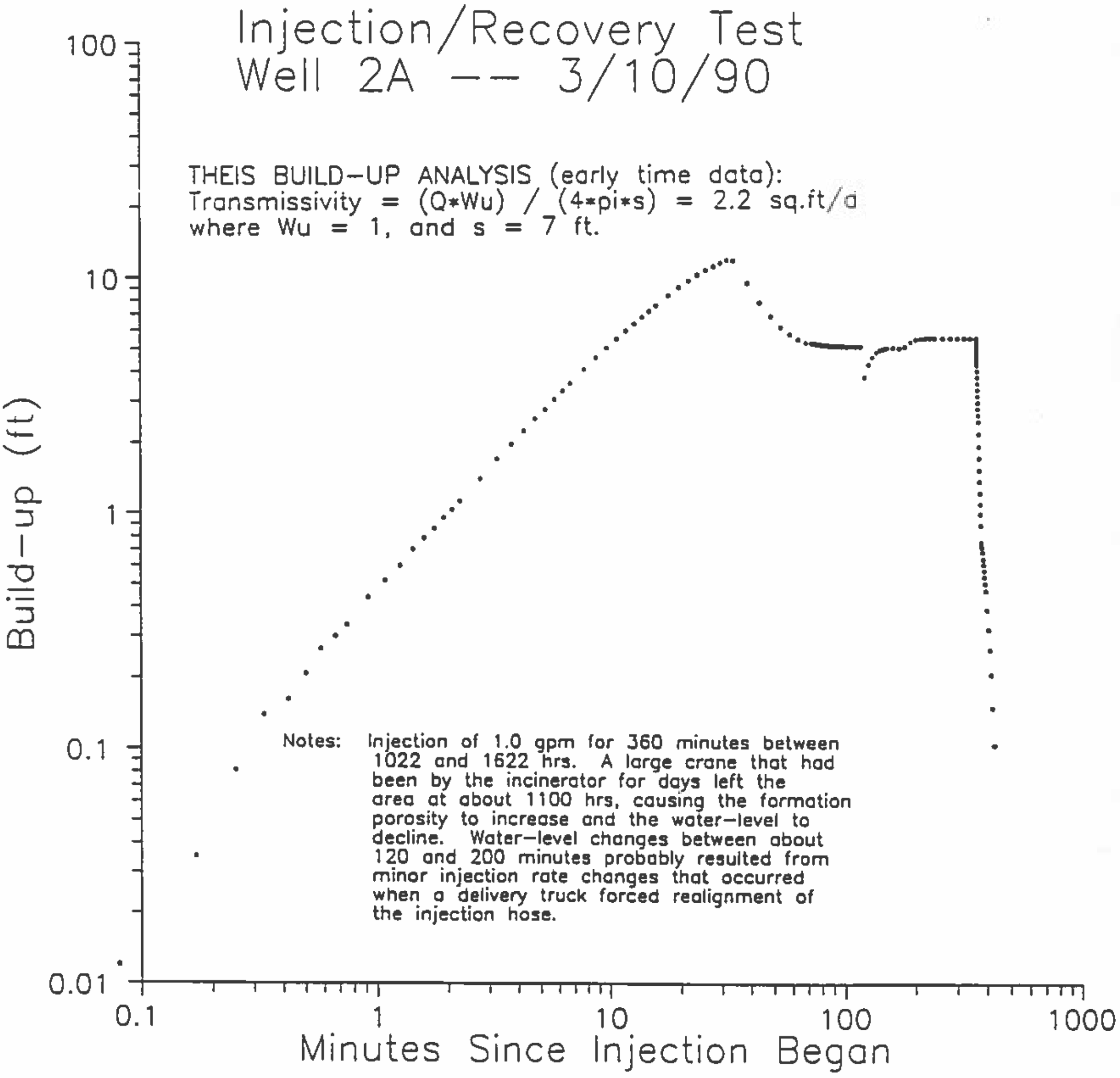

Figure 4.17b. Pumping test results at well MW-2A.

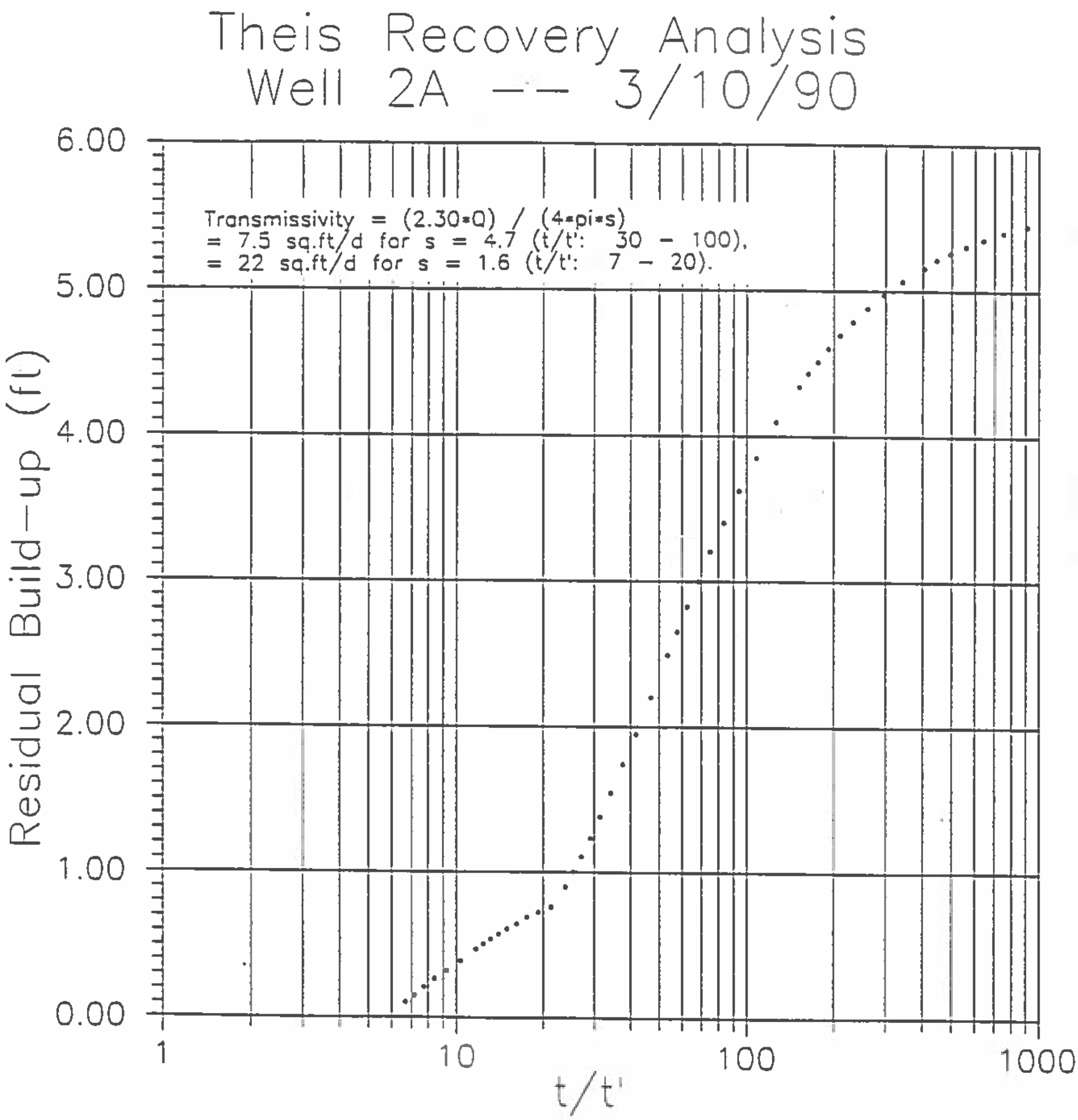

Figure 4.17c. Pumping test results at well MW-2A.

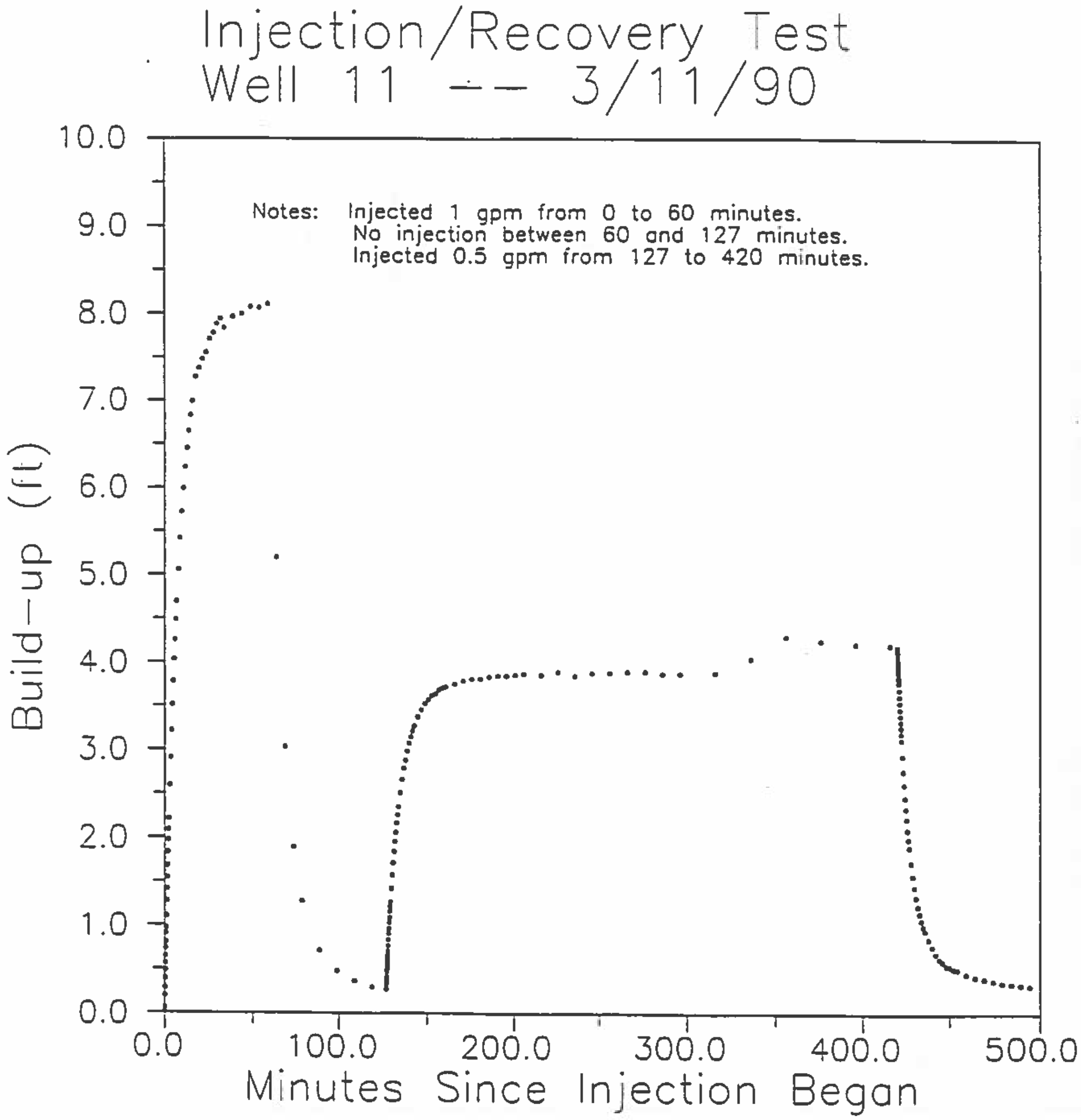

Figure 4.18a. Pumping test results at well MW-11.

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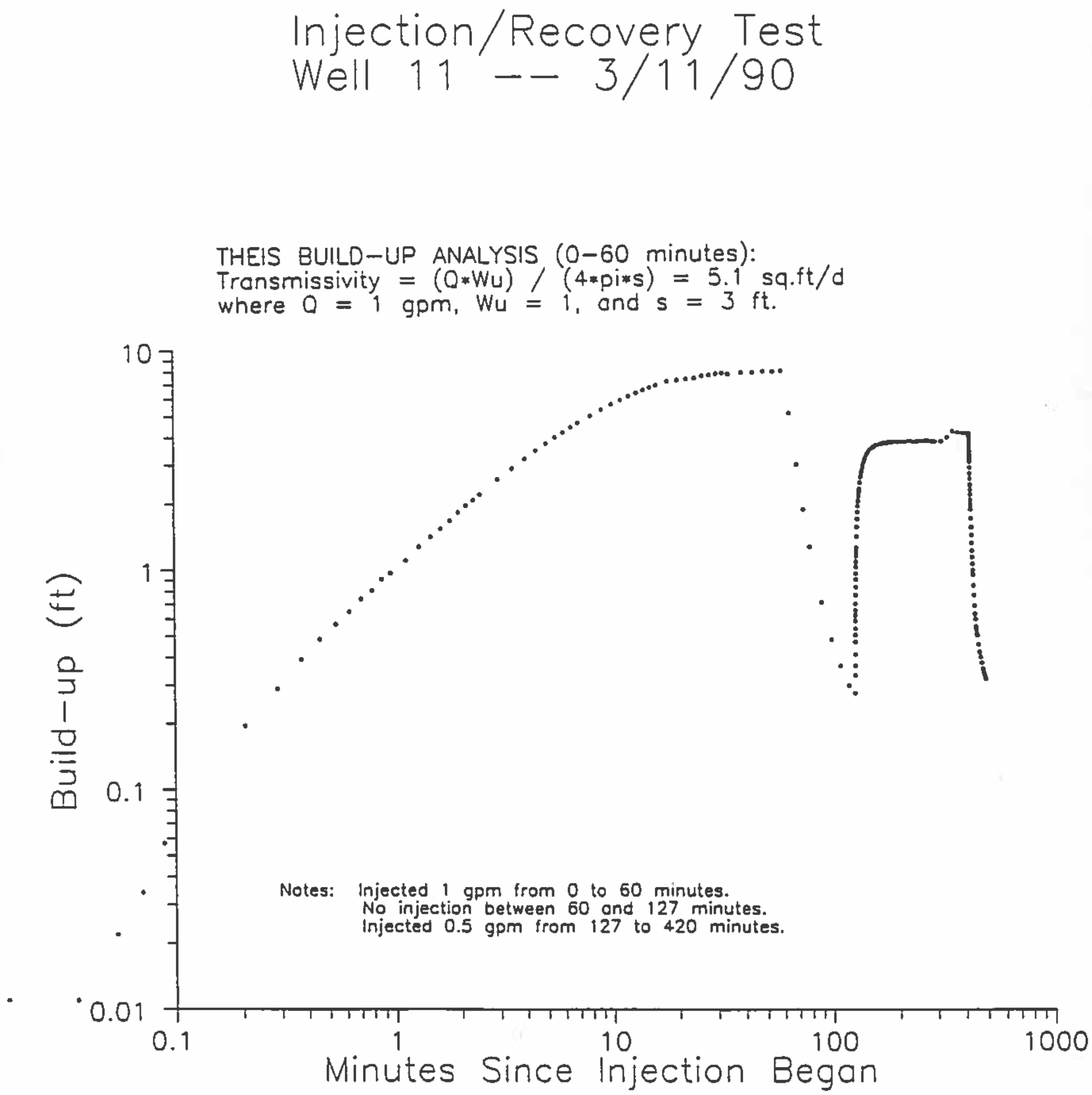

Figure 4.18b. Pumping test results at well MW-11.

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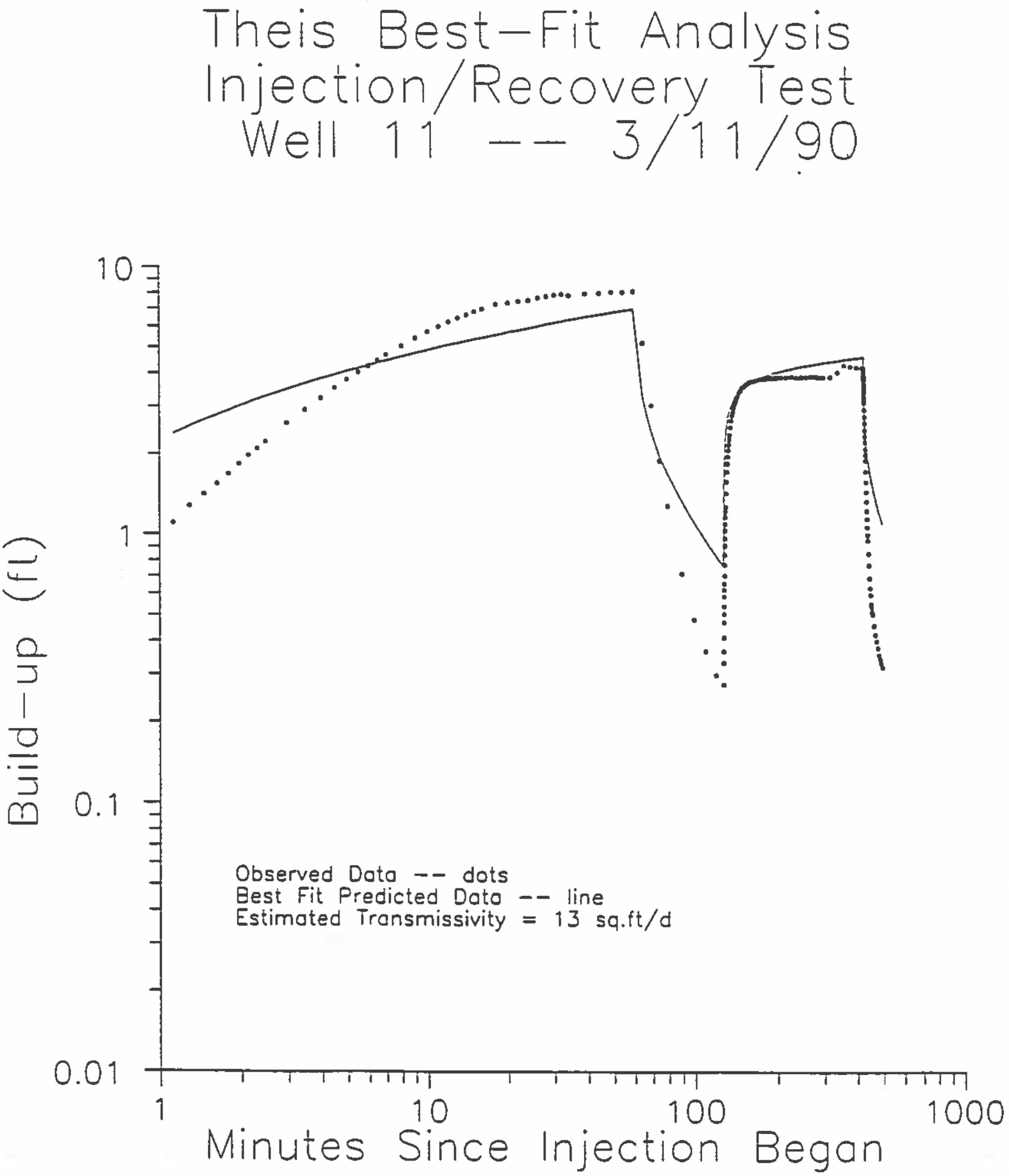

Figure 4.18c. Pumping test results at well MW-11.

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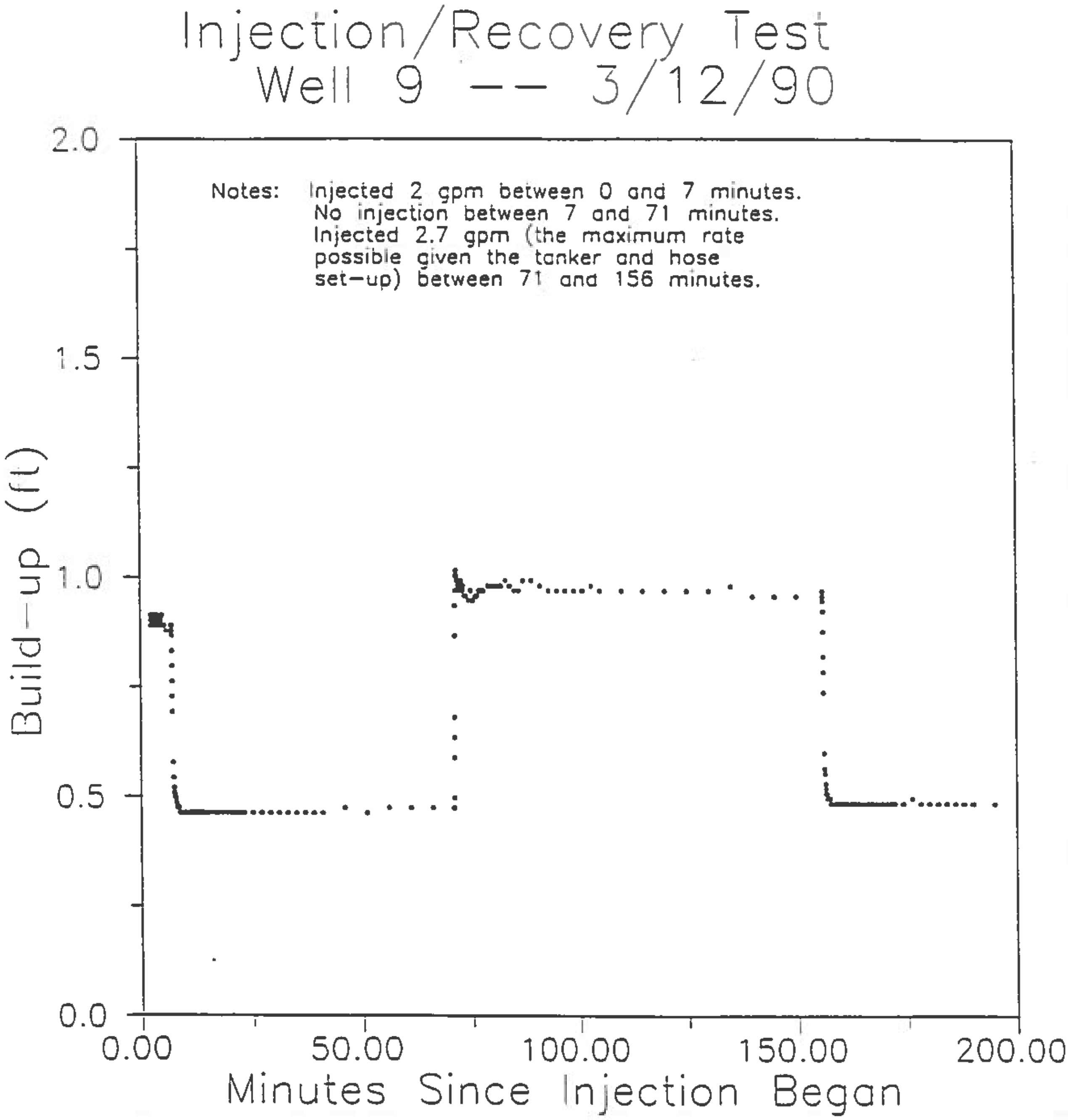

Figure 4.19a. Pumping test results at well MW-9.

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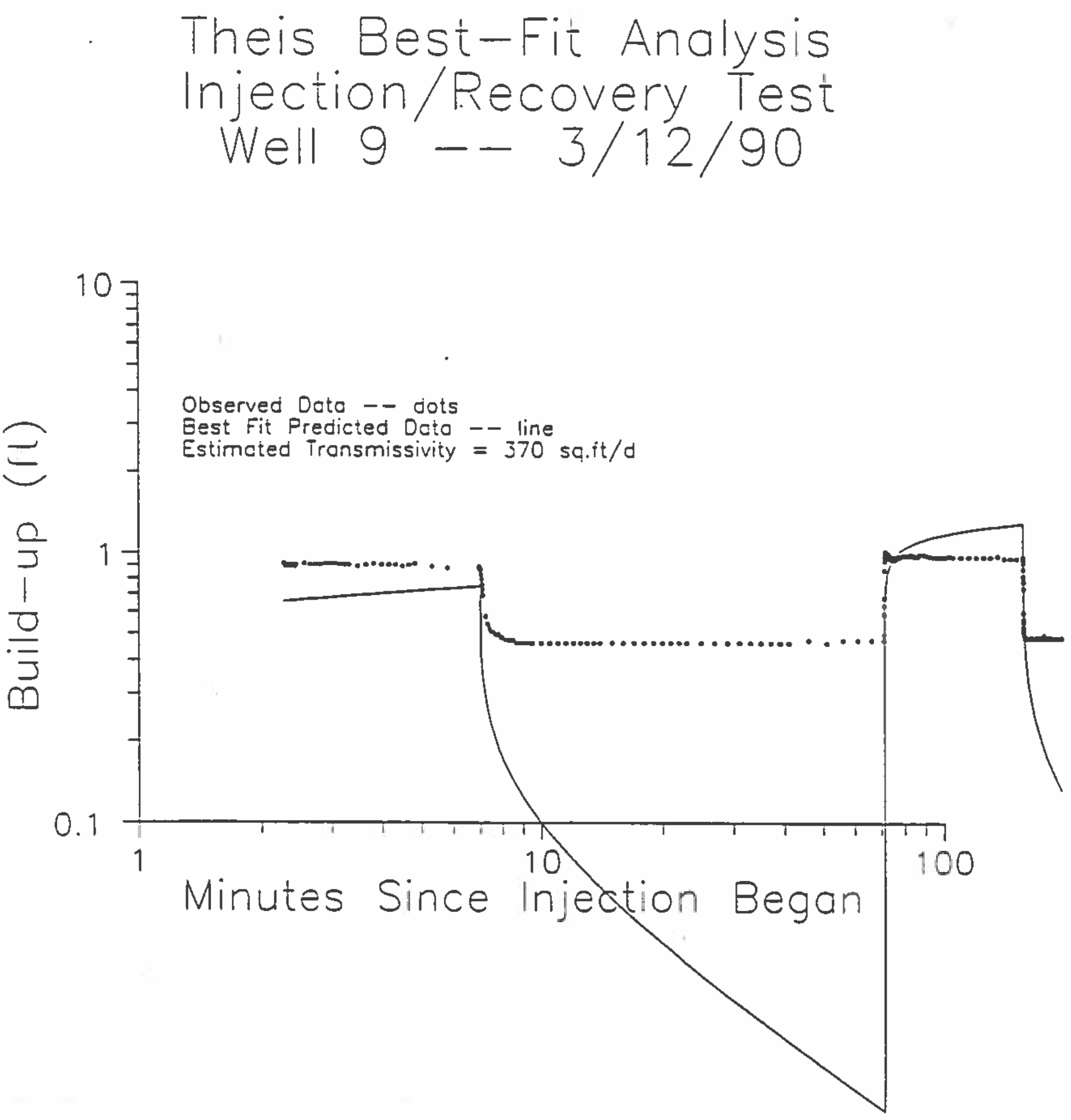

Figure 4.19b. Pumping test results at well MW-9.

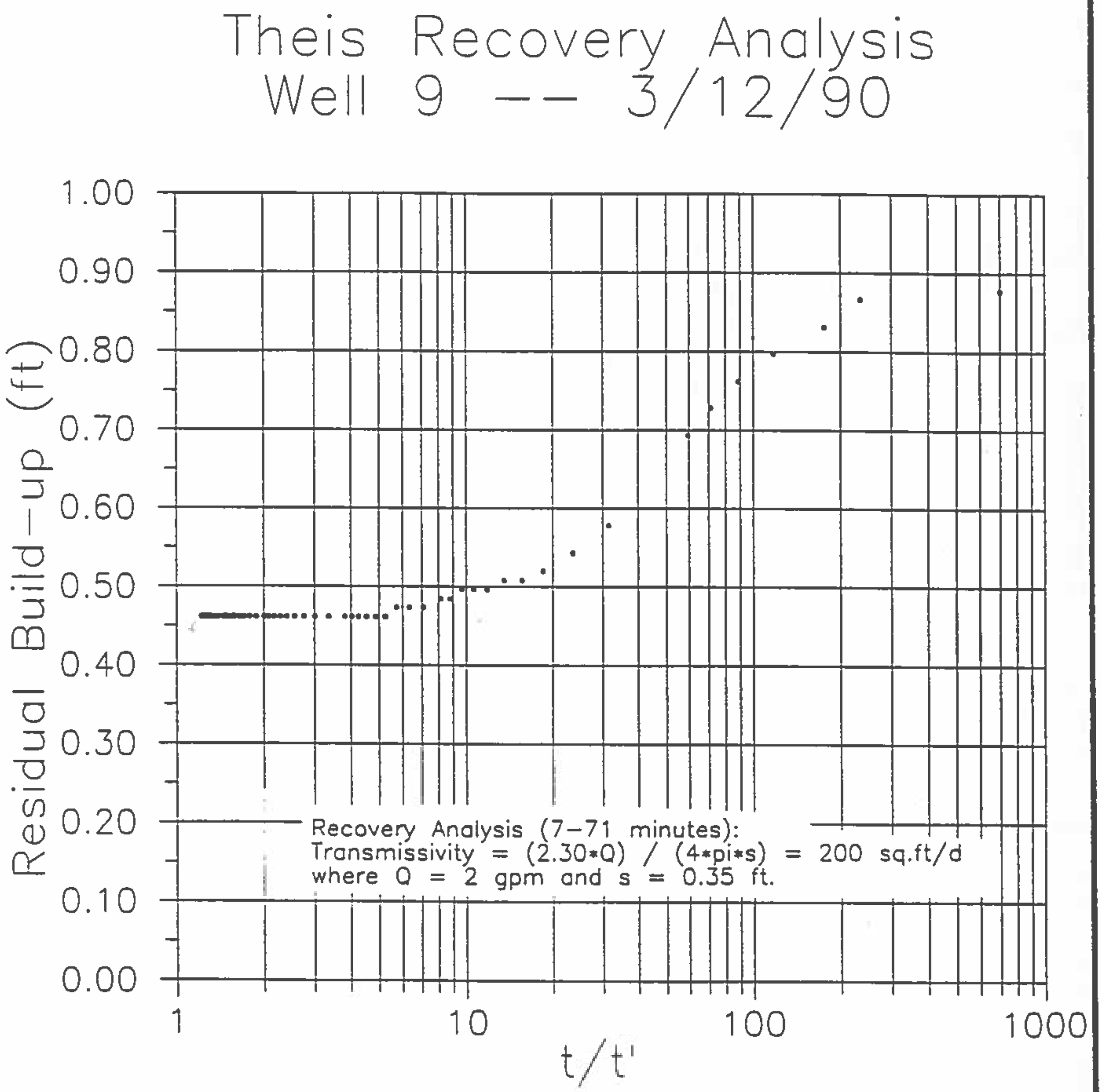

Figure 4.19c. Pumping test results at well MW-9.

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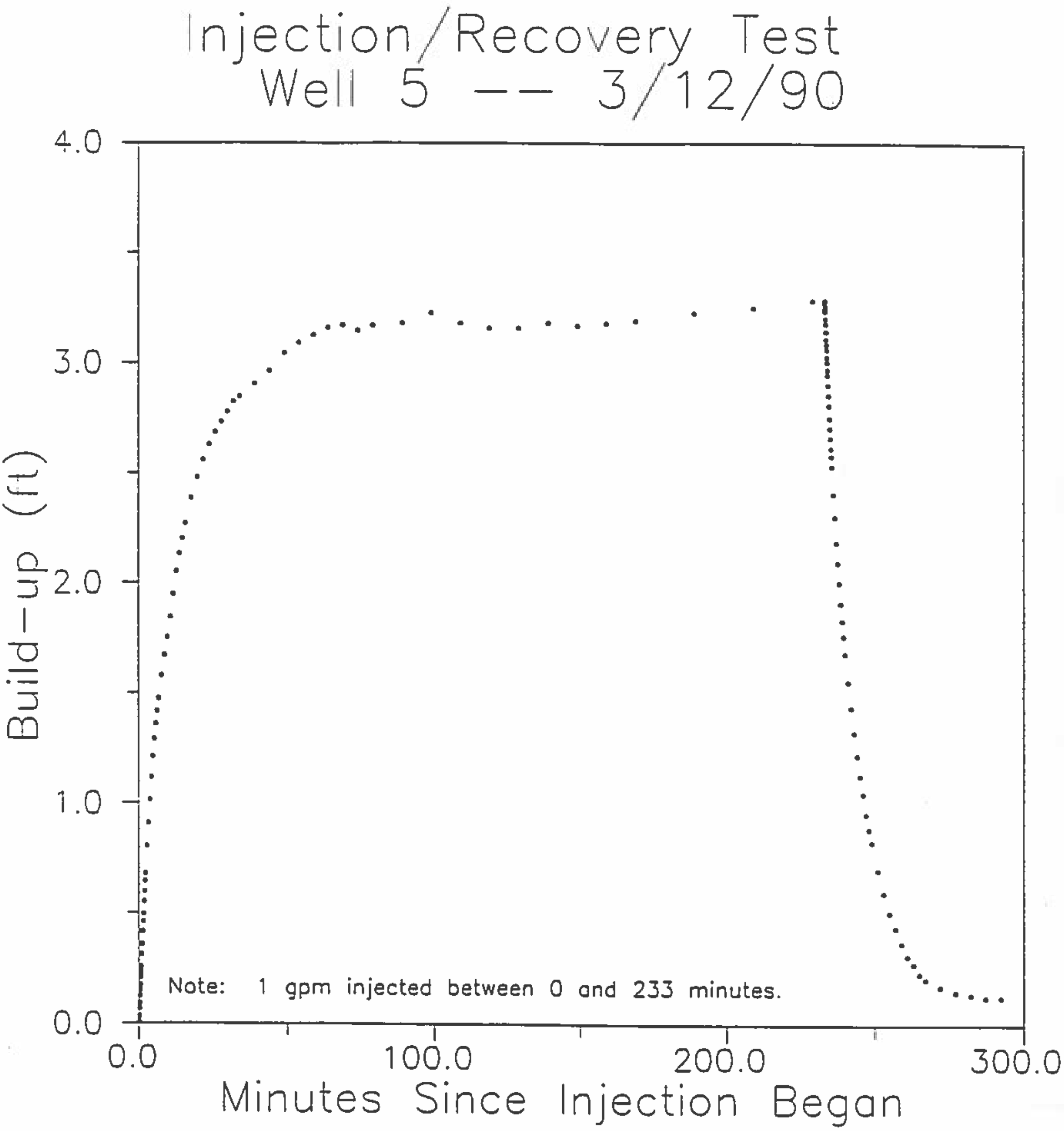

Figure 4.20a. Pumping test results at well MW-5.

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P8788-016/OA/10

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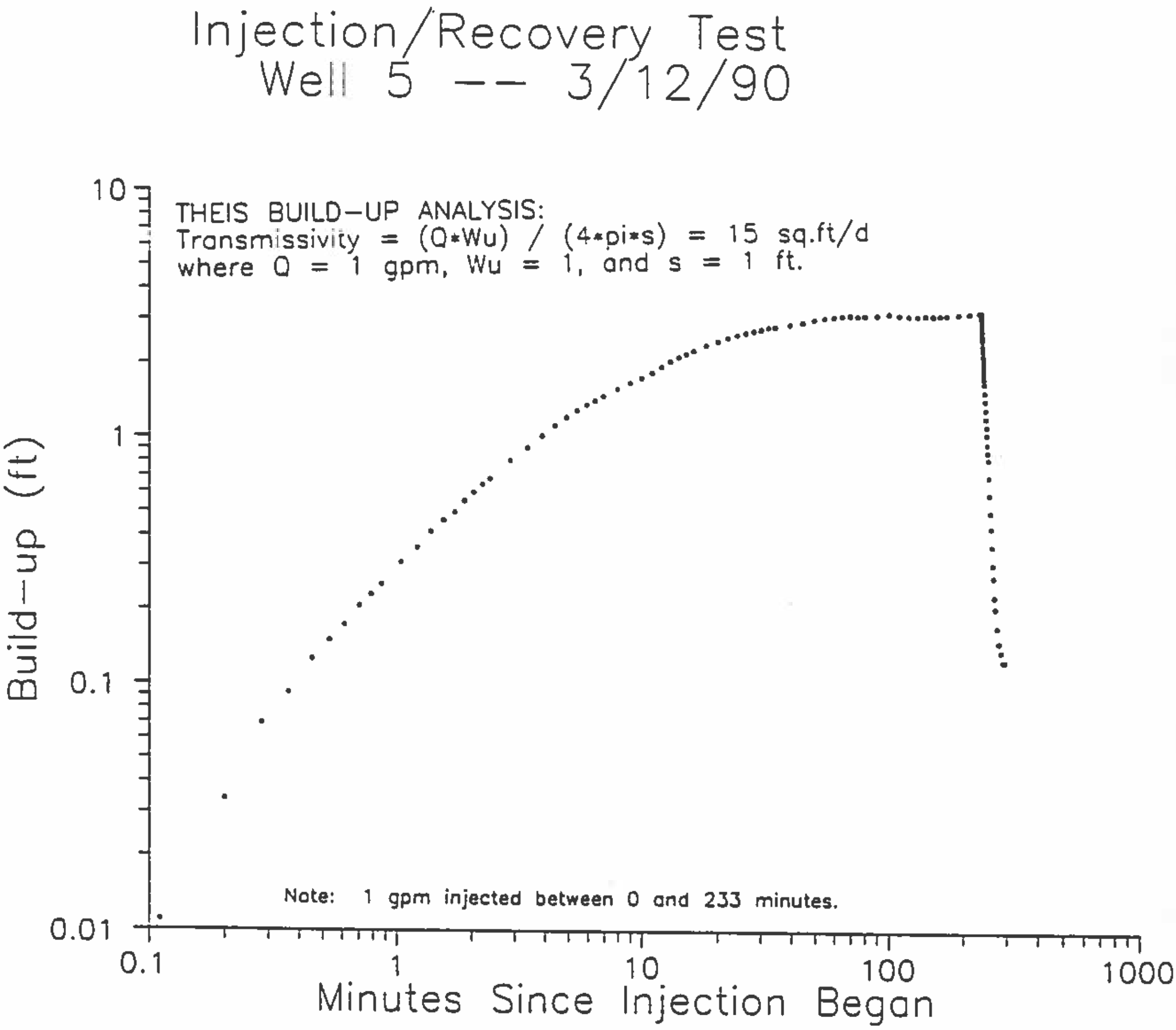

Figure 4.20b. Pumping test results at well MW-5.

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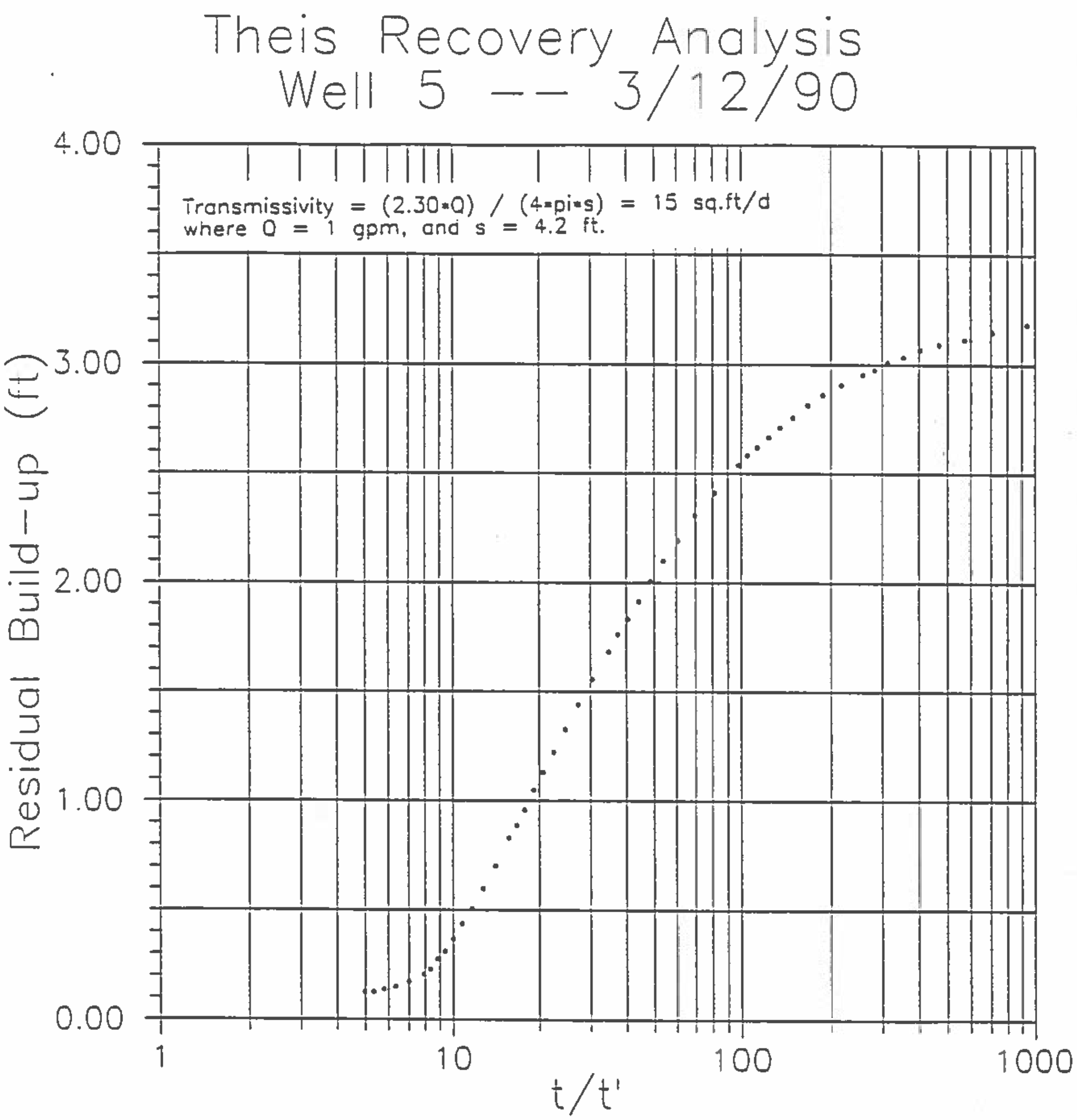

Figure 4.20c. Pumping test results at well MW-5.

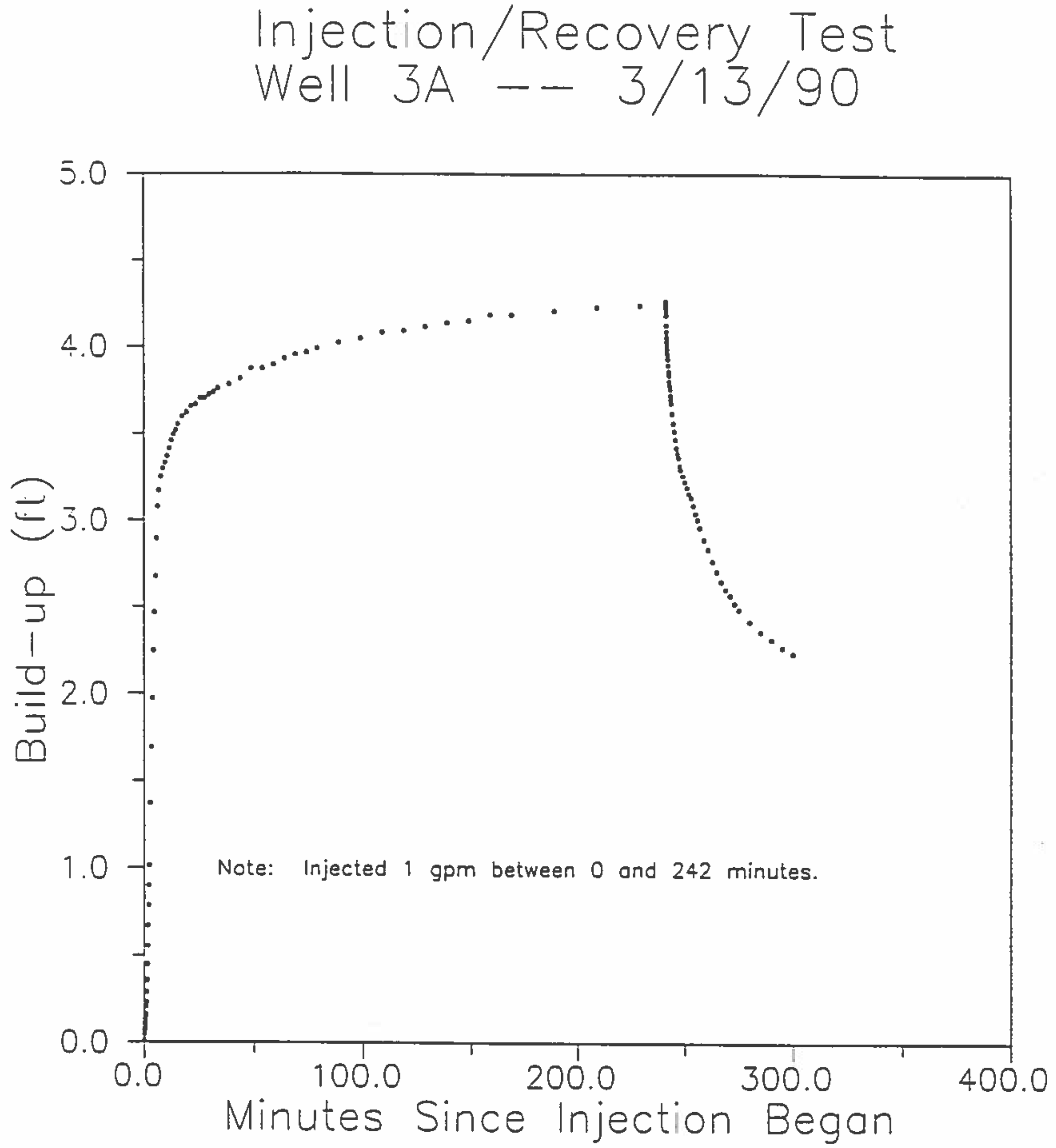

Figure 4.21a. Pumping test results at well MW-3A.

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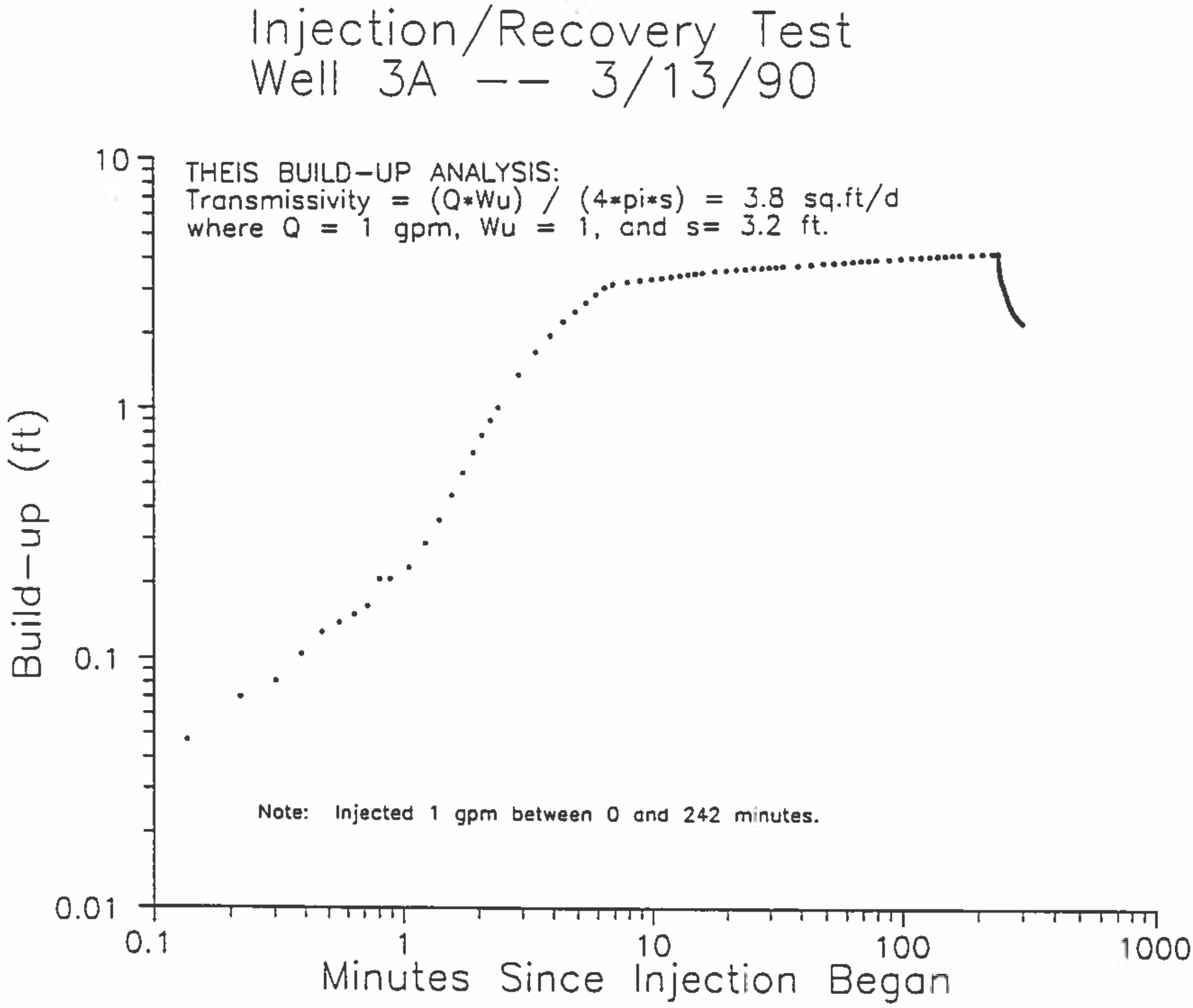

Figure 4.21b. Pumping test results at well MW-3A.

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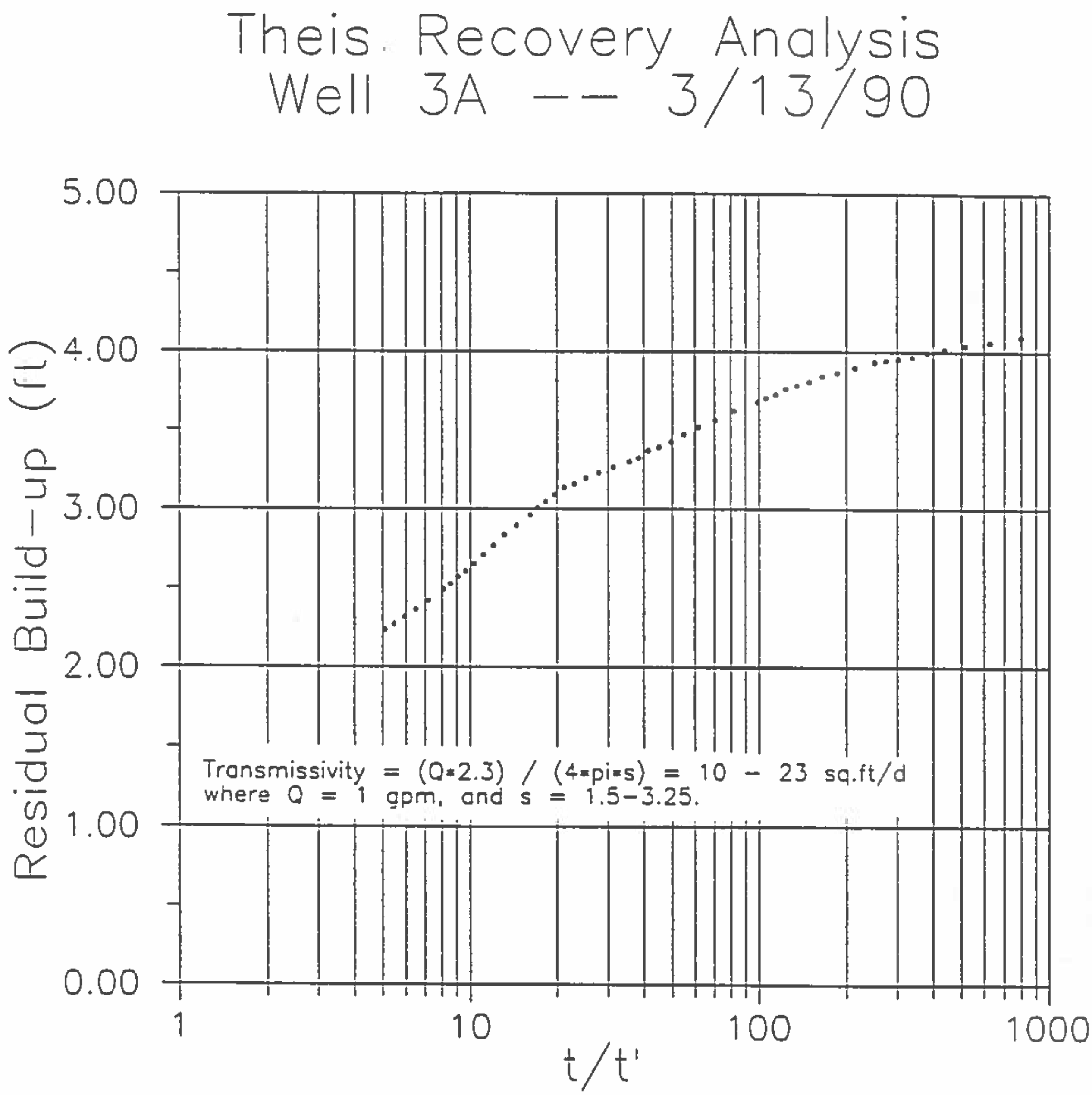

Figure 4.21c. Pumping test results at well MW-3A.

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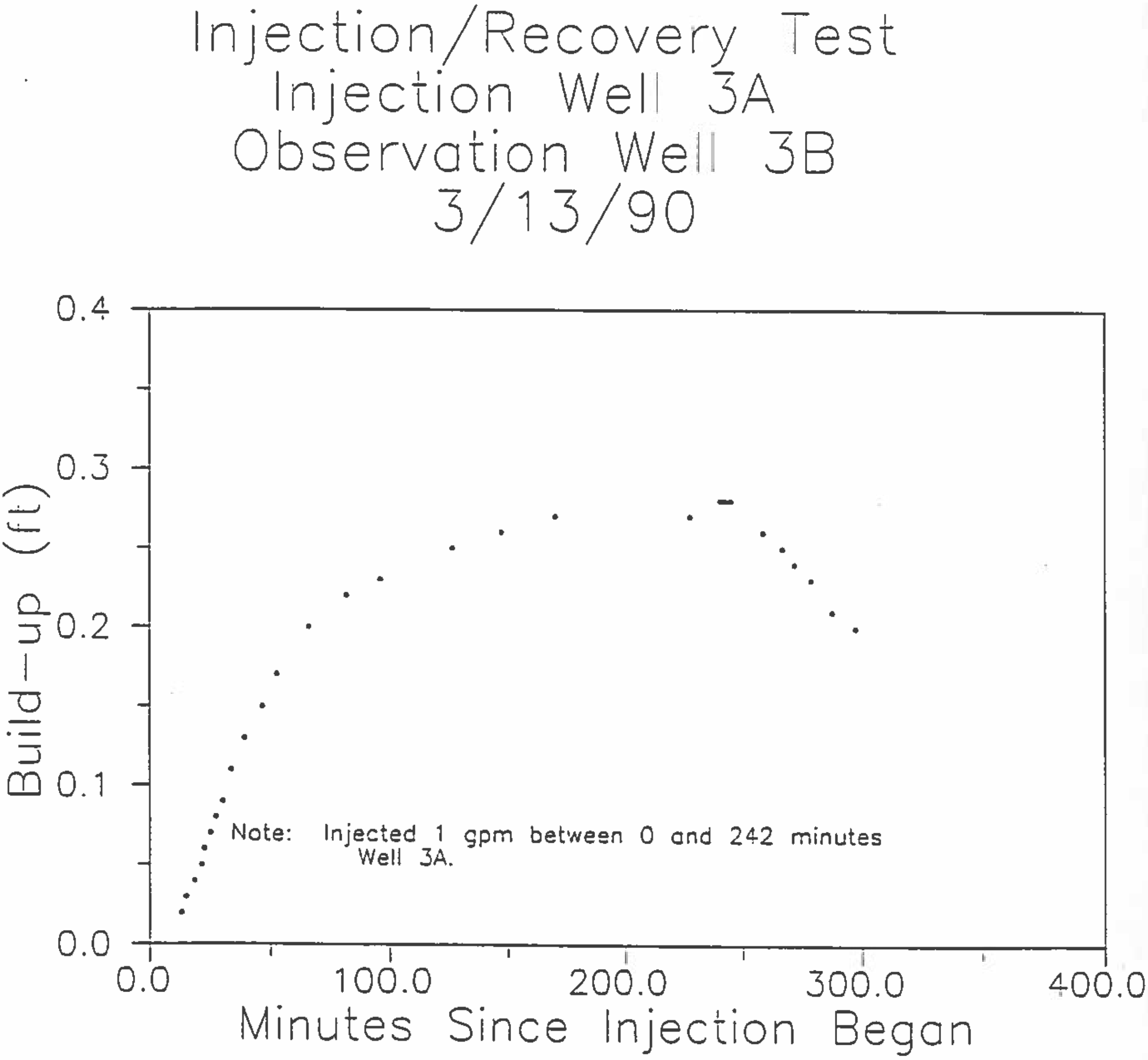

Figure 4.21d. Pumping test results at well MW-3A.

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P8788-016/OA/16

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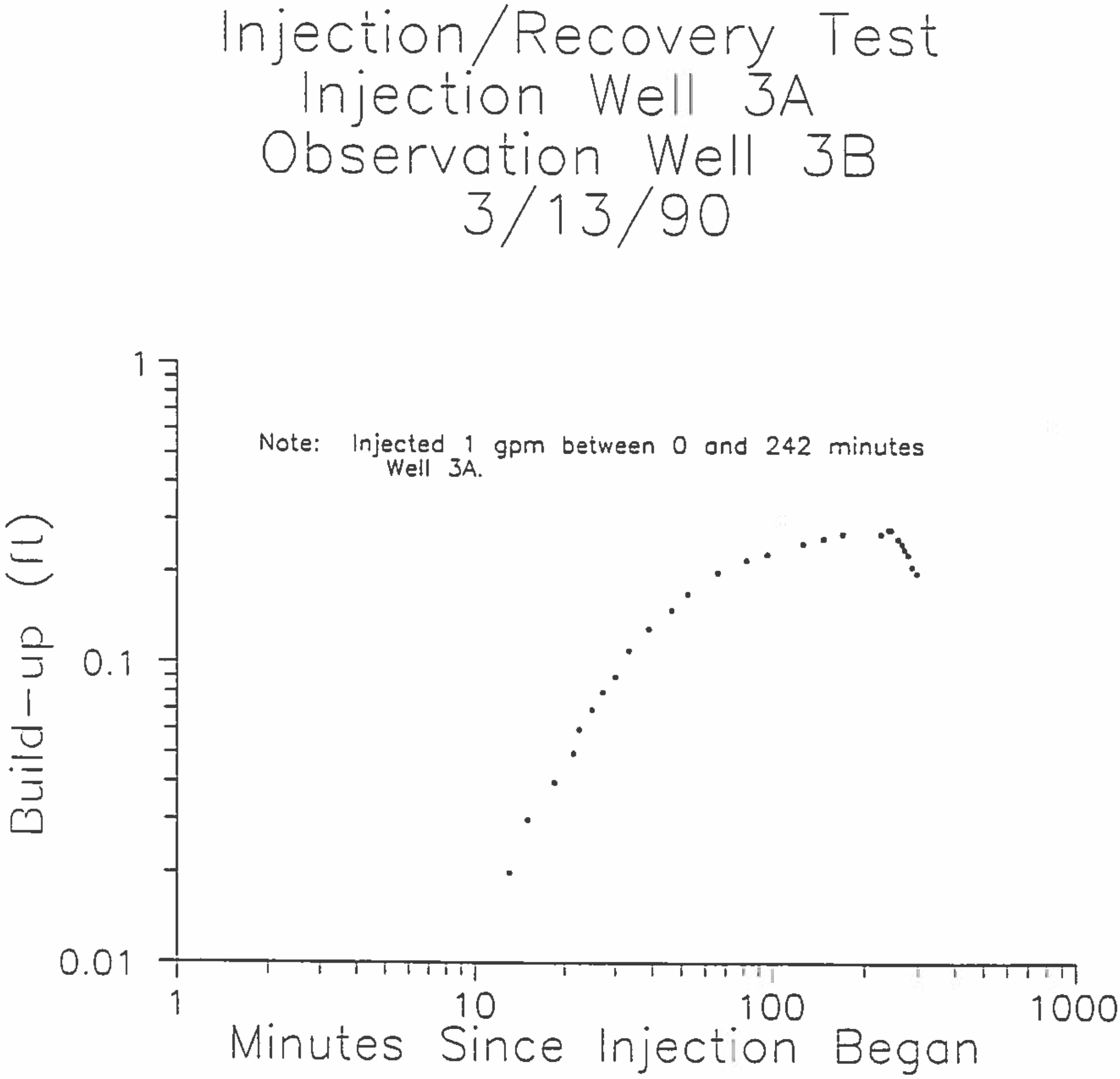

Figure 4.21e. Pumping test results at well MW-3A.

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Table 4.7. Summary of Injection/Recovery Test Results.

Injection Well	Transmissivity (ft^2/d)	Storage Coefficient	Method
2A	2.2	--	1
2A	7.5 - 22	--	2
11	5.1	--	1
11	13	--	3
9	370	--	3
9	200	--	2
5	15	--	1
5	15	--	2
3A	3.8	--	1
3A	10 - 23	--	2
3B	73	0.013	1

Method: 1 = Theis equation (Reed, 1980)
2 = Theis recovery equation (Kruseman and DeRidder, 1976)
3 = Least-squares best-fit analysis based on superposition of the Theis equation

the optical brightener. The locations of the injection sites and monitoring points are shown in Figure 4.22.

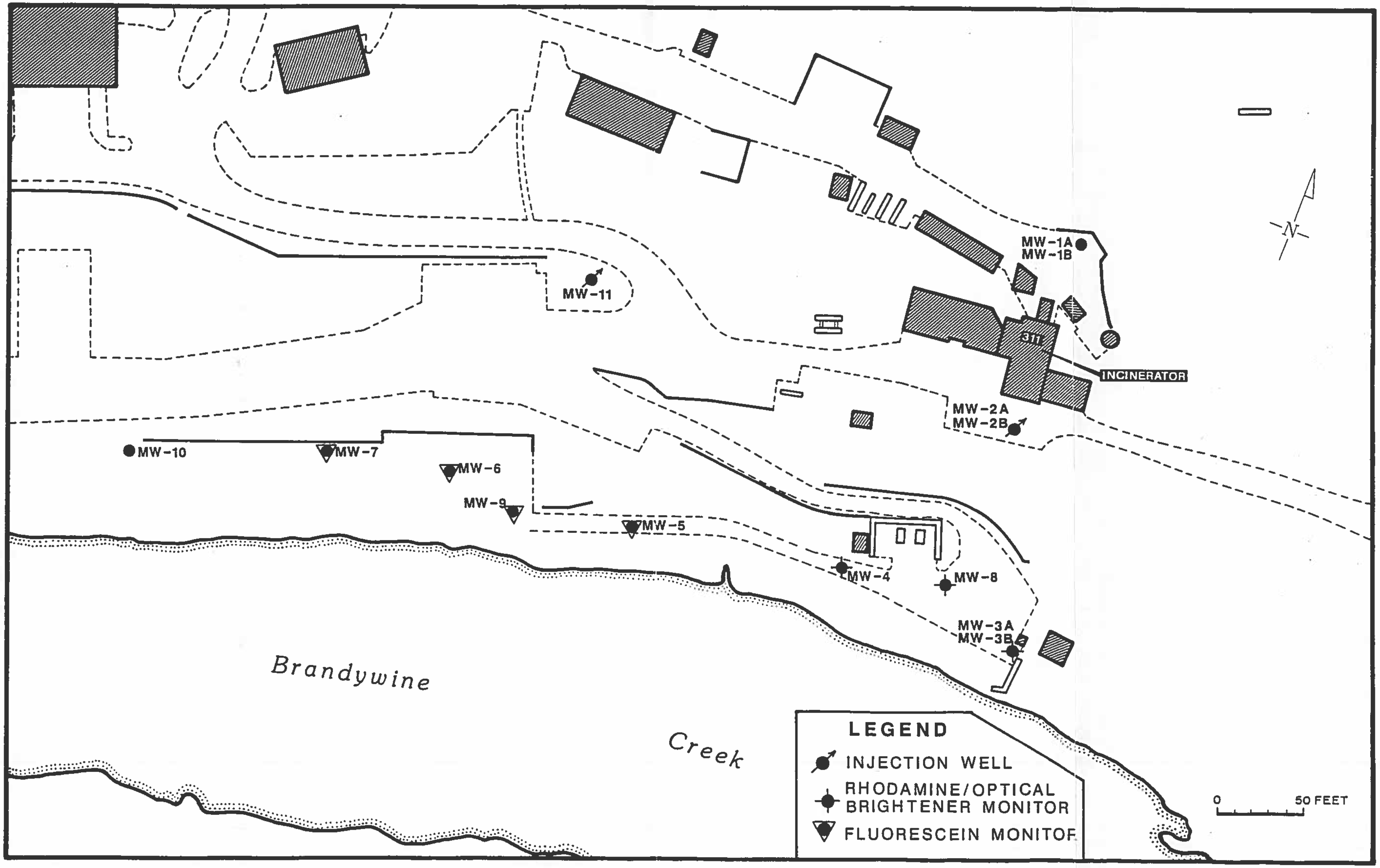
The tracer study was qualitative in scope. The identification of point-to-point connections between input and recovery points was the major goal of this study. However, the study was also designed to provide some quantitative information (i.e., precise dye concentrations) that could be applied to the evaluation of contaminant transport characteristics, including persistence, dispersion rates, and concentration.

The following tracer dyes were injected, in the quantities shown below, on March 19, 1990:

Dye	Amount	Injection Site
Rhodamine WT (20% solution)	4 ounces	MW-2A
Fluorescein	2 ounces	MW-2B
Optical Brightener	7 ounces	MW-11

These dye quantities were selected to provide a detectable amount of dye at the recovery points, but remain below visible levels.

All dyes were mixed in 55-gallon drums prior to placement in the wells. All dyes were handled with dedicated mixing equipment to minimize the potential for false positive traces and questionable interpretations. Approximately 40 gallons of Rhodamine WT dye solution, 12 gallons of Fluorescein dye solution, and 35 gallons of optical brightener dye solution were added to the respective wells. The Rhodamine WT and Fluorescein solutions were added to the wells over a period of 20 minutes, and the optical brightener was added to the well over a period of about 60 minutes. The optical brightener was added over a longer period because of the low injection rate at which well MW-11 would accept the solution.



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P8788-016/OB/21

Figure 4.22. Well network for tracer tests.

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4.4.3.2 Dye Sampling

Sampling for the tracers was conducted on the following dates:

Date	Number of Days After Injection
3/19/90	Background prior to injection
3/20/90	1 day
3/21/90	2 days
3/23/90	4 days
3/26/90	7 days
3/29/90	10 days
4/02/90	14 days
4/09/90	21 days
4/20/90	32 days

Dye was monitored and recovered by:

- The collection of discrete water samples from selected wells; and
- The collection of passive dye detectors that had been placed in selected wells and seeps.

Discrete water samples were collected from wells MW-2A, MW-2B, MW-3A, MW-3B, MW-4, and MW-8 throughout the tracer study. The purpose of the water samples was to collect quantitative dye concentration information. The samples were collected from each well with a dedicated bailer. Purging the wells prior to sampling might have artificially accelerated the movement of tracer in the system. Consequently, samples were collected from each well without purging.

Two passive detectors were placed in selected wells and seeps throughout the tracer study: (1) an activated charcoal detector (for Rhodamine WT and Fluorescein) and (2) an unbleached cotton detector (for visual identification of the Rhodamine WT, Fluorescein, and the optical brightener). The activated charcoal detector consisted of a 2 x 2-inch packet made of fiberglass window screening, filled with 6 to 14 mesh activated carbon. The cotton detector consisted of the same type of packet filled with unbleached surgical cotton. The packets placed in the wells were suspended half-way through the water column in each well using nylon string. The packets placed in the seeps were submerged in small "seep pools" at the two locations where the seeps emerged from the stone retaining wall at the site.

Charcoal and cotton detectors were placed in wells MW-2A, MW-2B, MW-3A, MW-3B, MW-4, MW-8, the uphill seep, and the downhill seep. Cotton detectors only (for the detection of the optical brightener) were placed in wells MW-5, MW-6, MW-7, MW-10, and MW-11.

4.4.3.3 Sample Analysis

The samples collected during this tracer study were analyzed several different ways, including both qualitative and quantitative analysis.

The cotton packets were qualitatively analyzed by viewing the packets under a long-wave length ultra-violet light to determine the presence of fluorescence. Cotton that has absorbed dyes will characteristically fluoresce blue-white for the presence of optical brightener, canary yellow for the presence of Fluorescein, and orange for the presence of Rhodamine WT.

The carbon packets were both qualitatively and quantitatively analyzed. In the laboratory, the dye was qualitatively analyzed by first elutriating the carbon with an elutriant (alcohol-based) solution and visually checking for the characteristic dye color. The elutriant was then quantitatively analyzed with a Shimadzu spectrofluorophotometer. With this instrument, concentrations as low as 1 ug/l could be quantified. Discrete water samples were also quantitatively analyzed with this instrument. All dye handling, sampling, and analysis was done according to procedures presented in USEPA 904/6-88-01, Application of Dye-Tracing Techniques for Determining Solute-Transport Characteristics of Ground Water in Karst Terranes. All analyses were done by Lancaster Laboratories, Inc., Lancaster, Pennsylvania.

4.4.3.4 Results

The results of the tracer test are summarized in Tables 4.8 and 4.9 and are graphically presented in Figures 4.23, 4.24, and 4.25.

The results of the tracer study are varied. All qualitative analysis of the cotton packets indicated no visible fluorescence. Consequently, no optical brightener, Rhodamine WT or Fluorescein was visibly detected. In addition, no Fluorescein was detected in the discrete water and carbon samples collected from the seeps and wells beyond the injection points.

The Rhodamine WT appeared to move quickly through the system, as it was detected in carbon detectors in wells and seeps within 2 to 4 days. However this dye was not detected in discrete water samples obtained from most points, with the exception of well MW-3A (see Figure 4.25). At location MW-3A, the dye was detected 4 days after the injection.

4.5 GROUNDWATER SAMPLING

4.5.1 Water-Level Monitoring

Several rounds of water-level monitoring were performed at the site to assess groundwater flow gradients over time. Water-level measurements were made at each well prior to groundwater sampling in January and May. Additionally, two to three water-level surveys were conducted each month from January through April, 1990. Measurements were made using a hand-held electronic meter. All readings were made from the designated measuring point.

Water-levels from each survey are tabulated in Appendix E. These data were contoured to produce potentiometric surface maps for eleven surveys. Groundwater seep elevations, obtained from a site topographic map, were included with the contoured data set. The maps are provided in Figures 4.26 - 4.37. Note that data from well MW-10 has not been used in production of these maps. The slow, incomplete recovery after groundwater sampling in January and the extremely low hydraulic conductivity observed at well during slug tests indicate that this well

Table 4.8. Rhodamine WT constrations (parts per billion (ppb)) in the water sample.

Well #	Event 1* 3/19/90	Event 2 3/20/90	Event 3 3/21/90	Event 4 3/23/90	Event 5 3/26/90	Event 6 3/29/90	Event 7 4/2/90	Event 8 4/9/90	Event 9 4/20/90
MW-3A	<1	<1	<1	4.0	17	33	28	29	38
MW-3B	<1	<1	<1	1	<1	<1	<1	<1	<1
MW-4	1	<1	<1	<1	<1	<1	<1	<1	<1
MW-8	<1	<1	1	<1	2	1	<1	<1	<1

* Background sample

Table 4.9. Rhodamine WT constrations (parts per billion (ppb)) in the carbon sample.

Well #	Event 1* 3/19/90	Event 2 3/20/90	Event 3 3/21/90	Event 4 3/23/90	Event 5 3/26/90	Event 6 3/29/90	Event 7 4/2/90	Event 8 4/9/90	Event 9 4/20/90
MW-2A	--	--	7,760	71,400	--	44,400	24 (J)	24,100	47,100
MW-3A	5	8	15	173	154	196	261	100	29
MW-3B	12	18	14	154	71	117	24	14	12
MW-4	5	20	17	6	66	25	18	22	10
MW-8	5	15	13	12	100	75	(A)	11	11
Uphill Seep	7	13,900 (J)	7	102	28	83	21	16	12
Downhill Seep	8	10	4	131	13	17	10	11	10

* Background sample
-- Sample not taken
(A)Sample lost
(J)Suspected data value

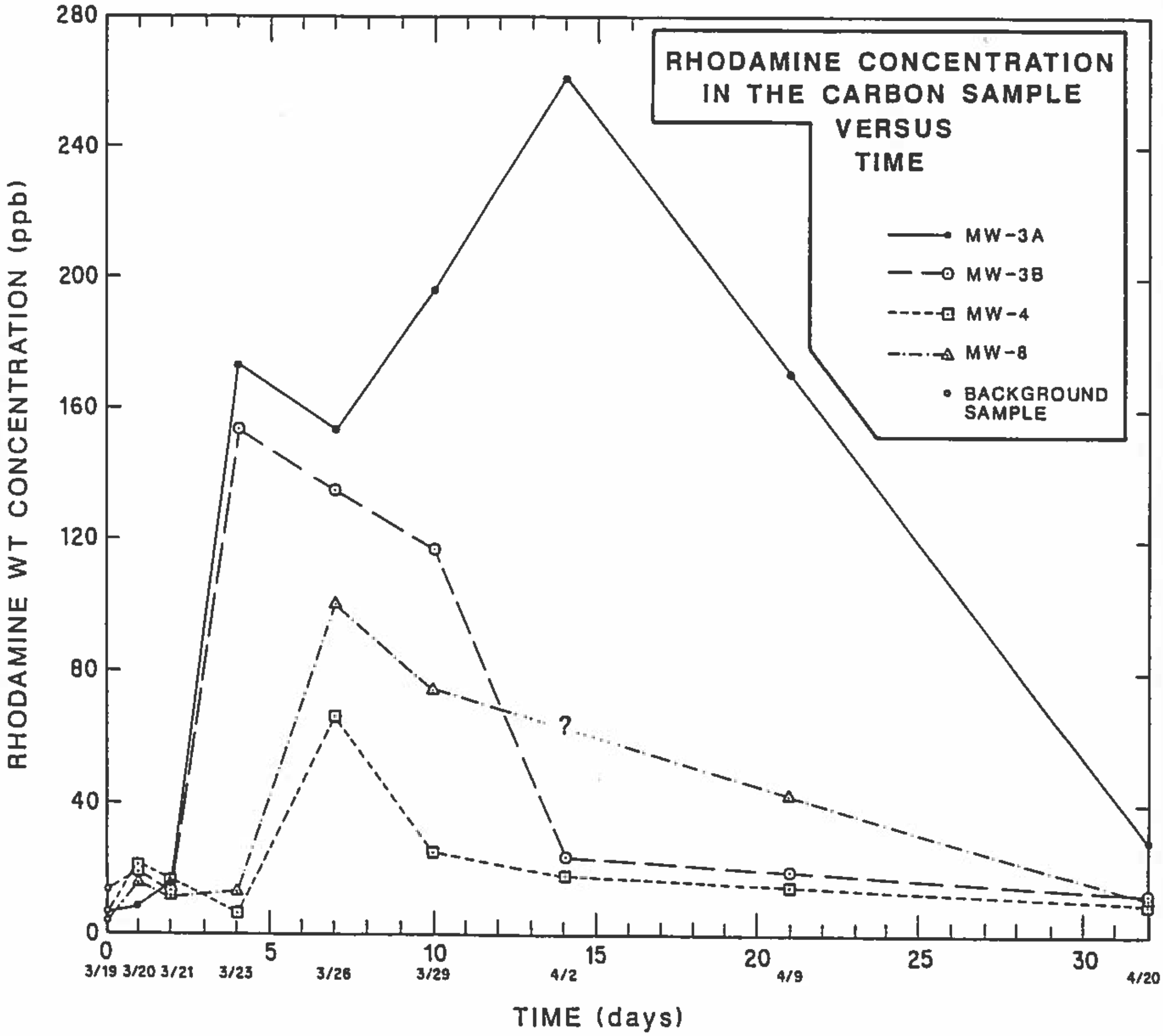

Figure 4.23. Tracer study results for carbon samples at monitor wells.

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P6788-016/OA/35

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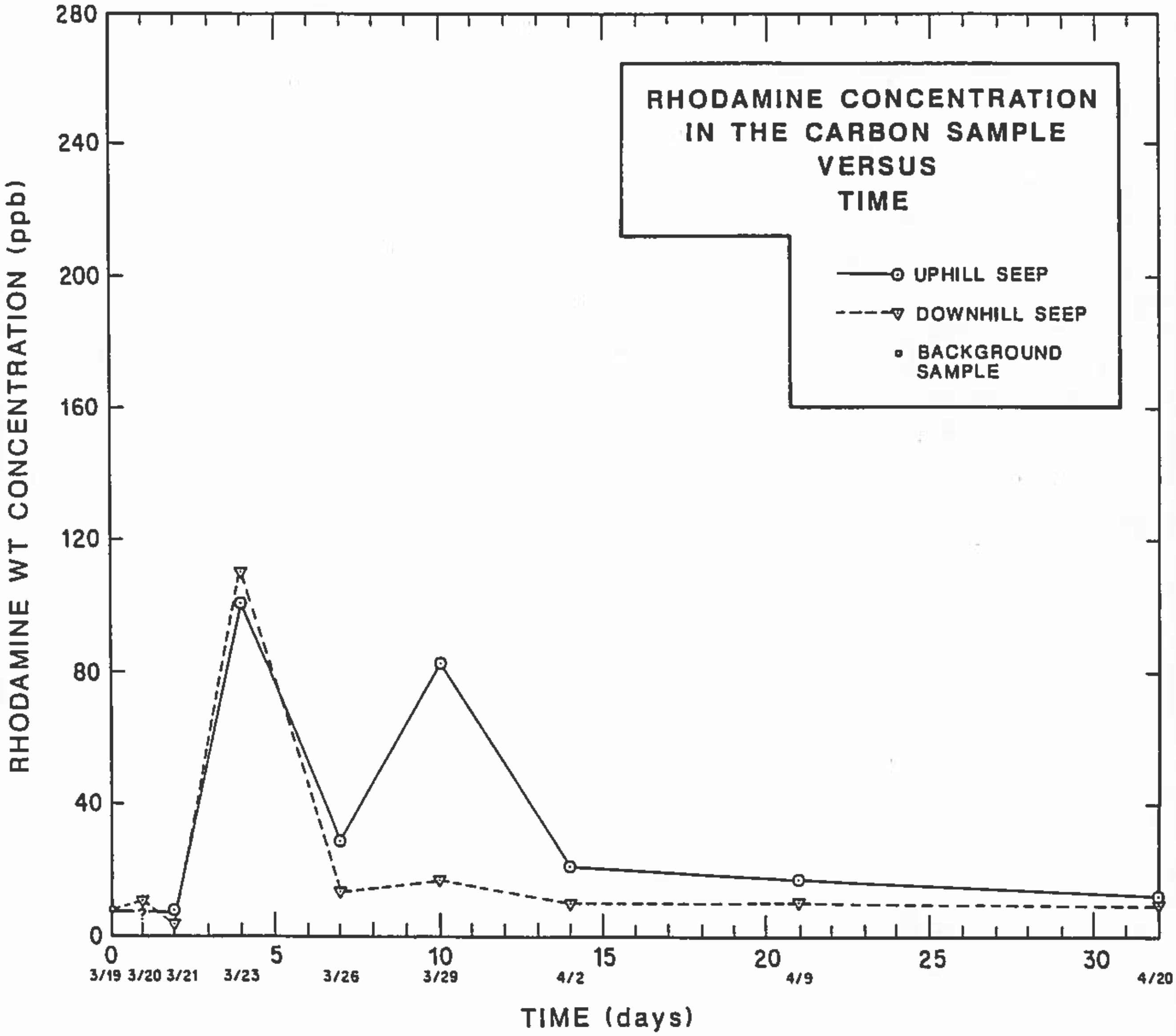

Figure 4.24. Tracer study results at groundwater seeps.

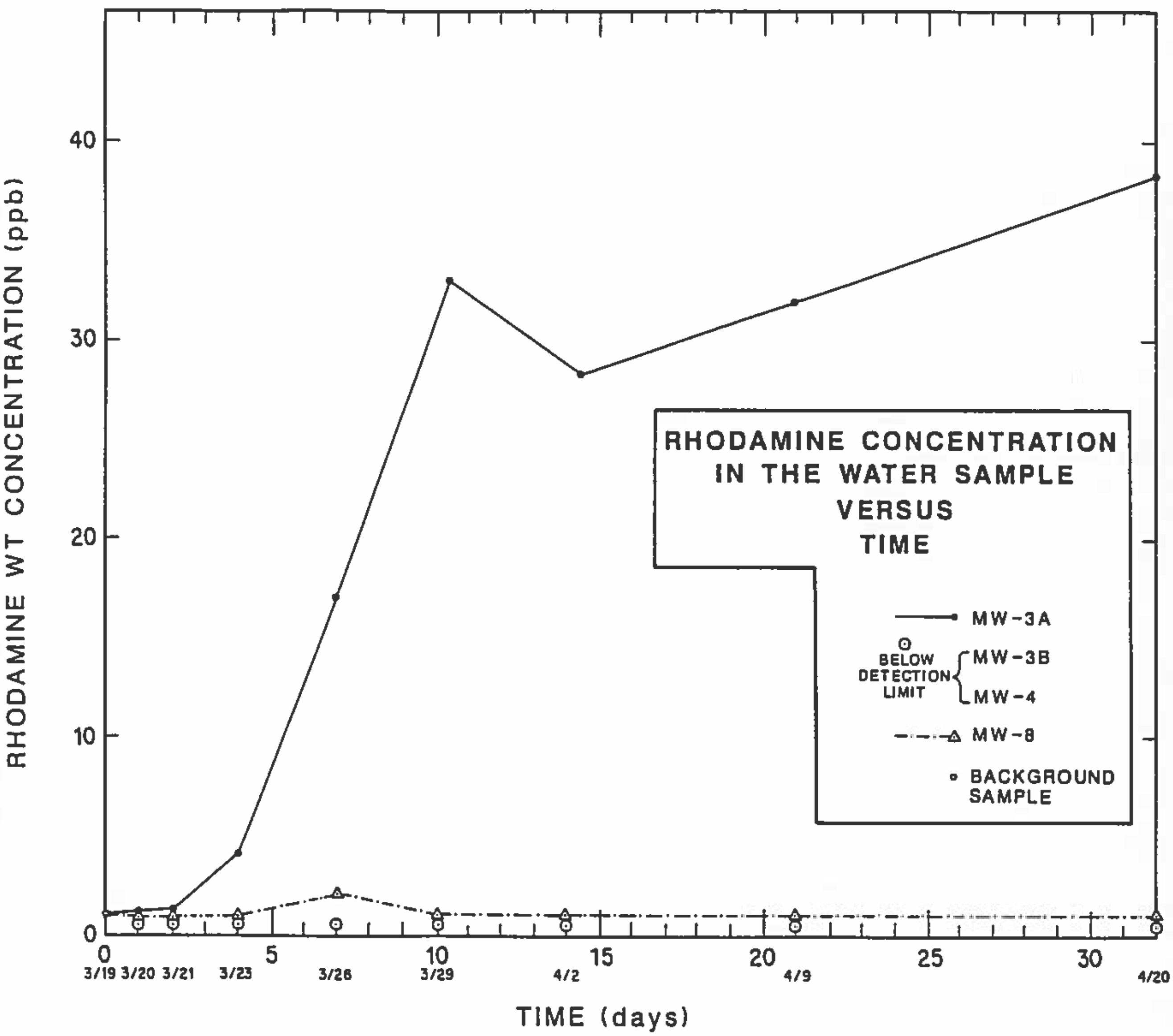

Figure 4.25. Tracer study results for water samples from wells.

GeoTrans / Tetra Tech
P8788-016/OA/18

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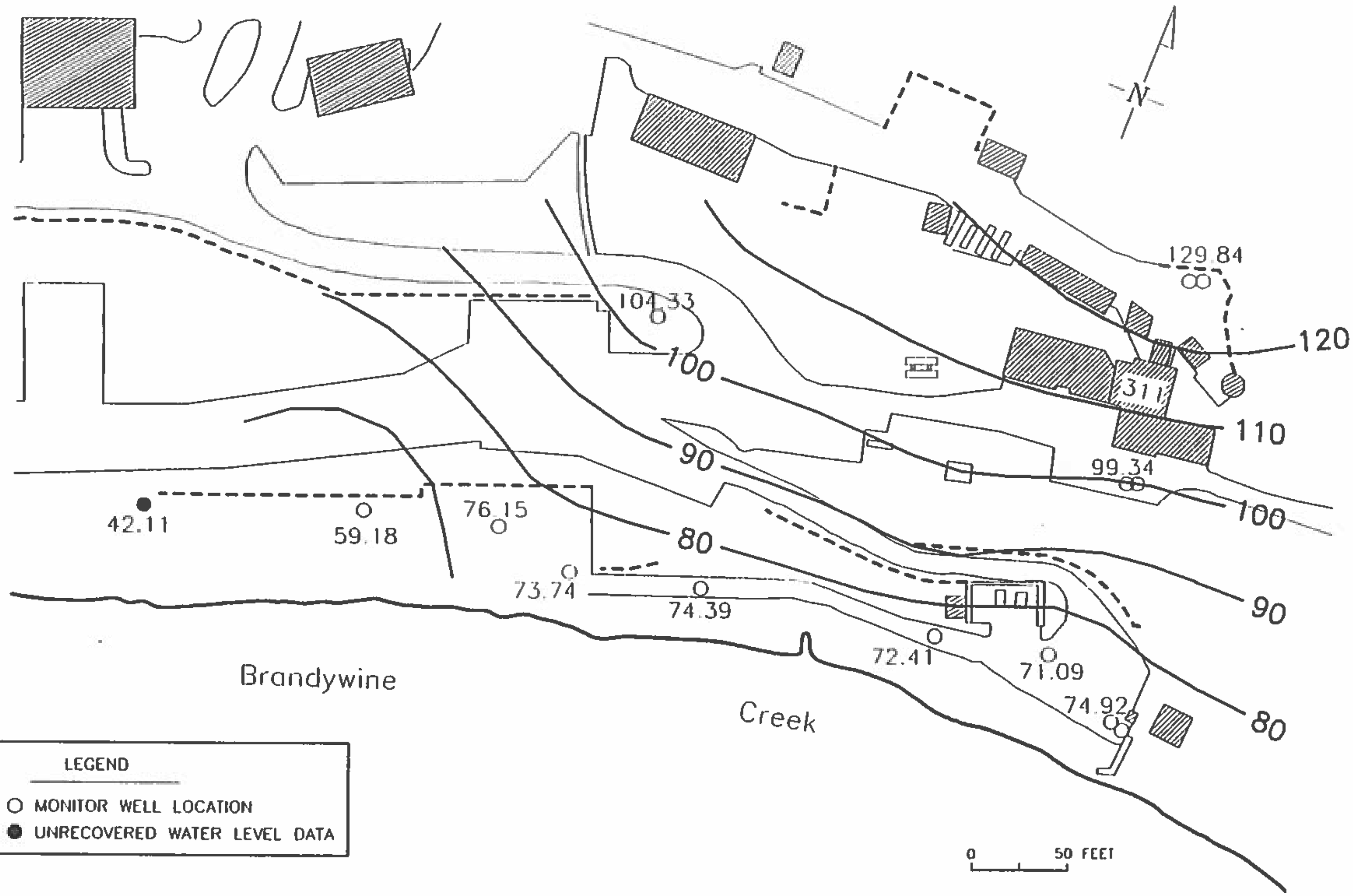

Figure 4.26. Potentiometric surface map - January 3, 1990, water-level survey.

GeoTrans / Tetra Tech
P8788-016/OA/23

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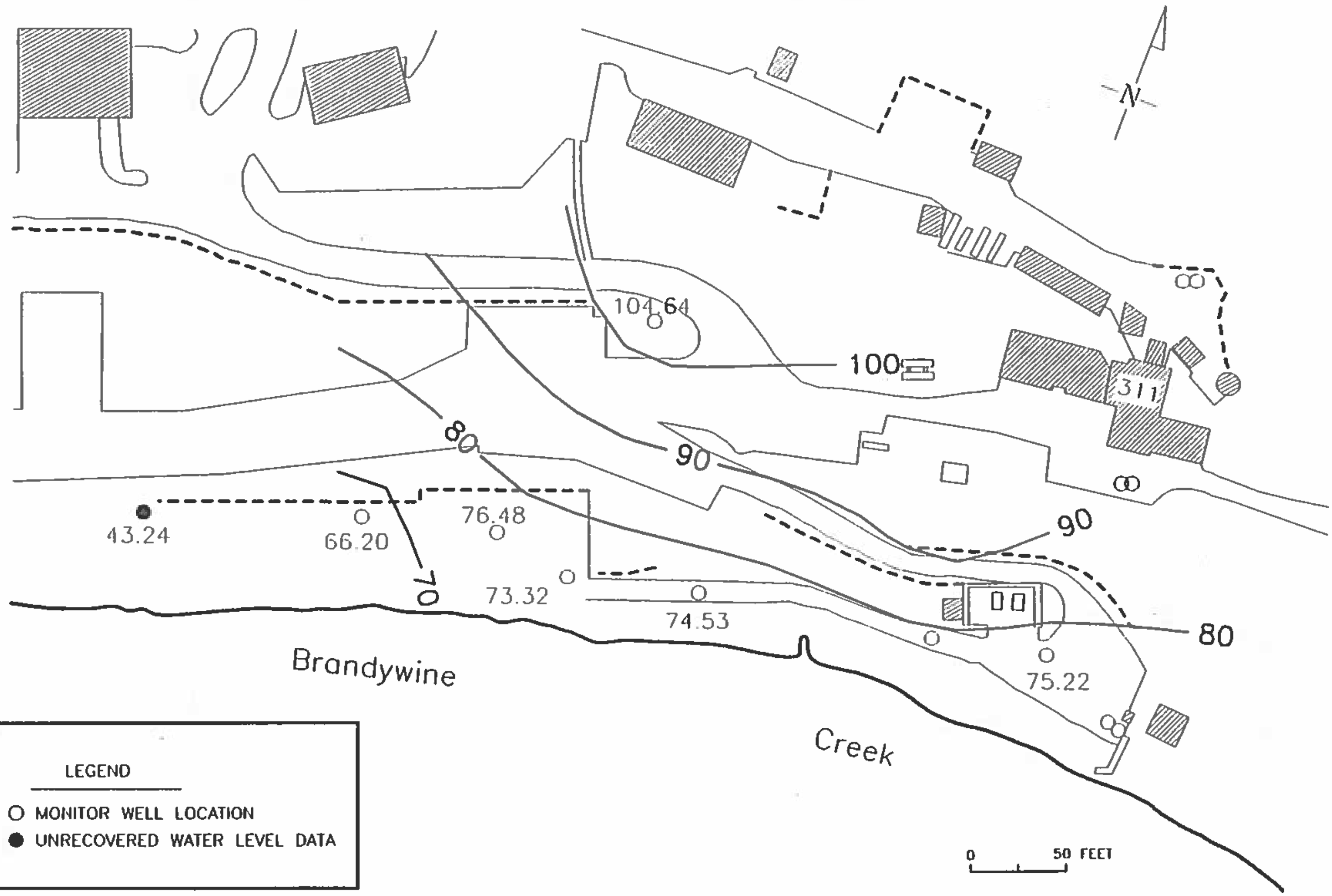

Figure 4.27. Potentiometric surface map - January 10, 1990, water-level survey.

GeoTrans / Tetra Tech
P8788-016/OA/24

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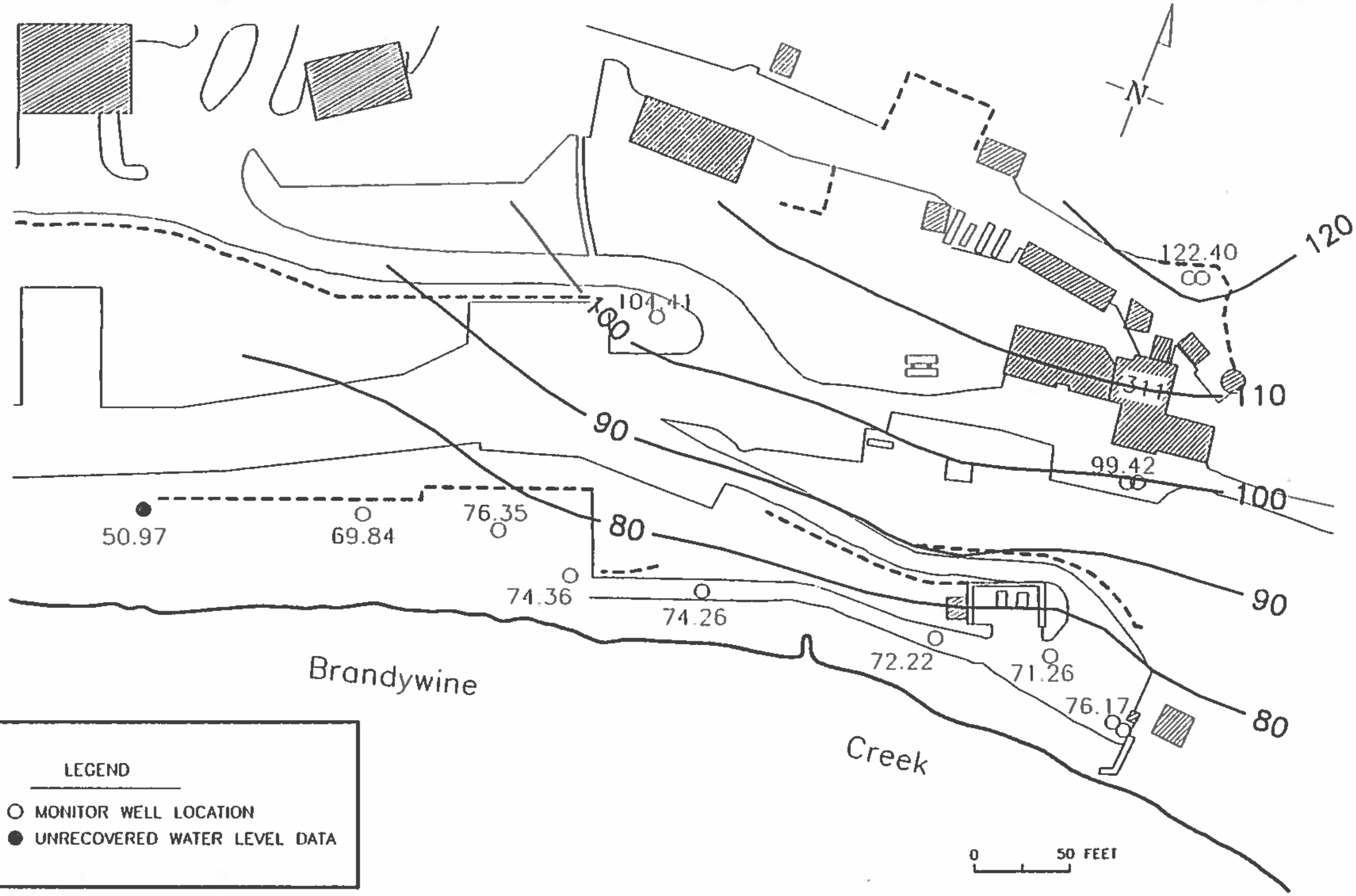

Figure 4.28. Potentiometric surface map - February 2, 1990, water-level survey.

GeoTrans / Tetra Tech
P8788-016/OA/25

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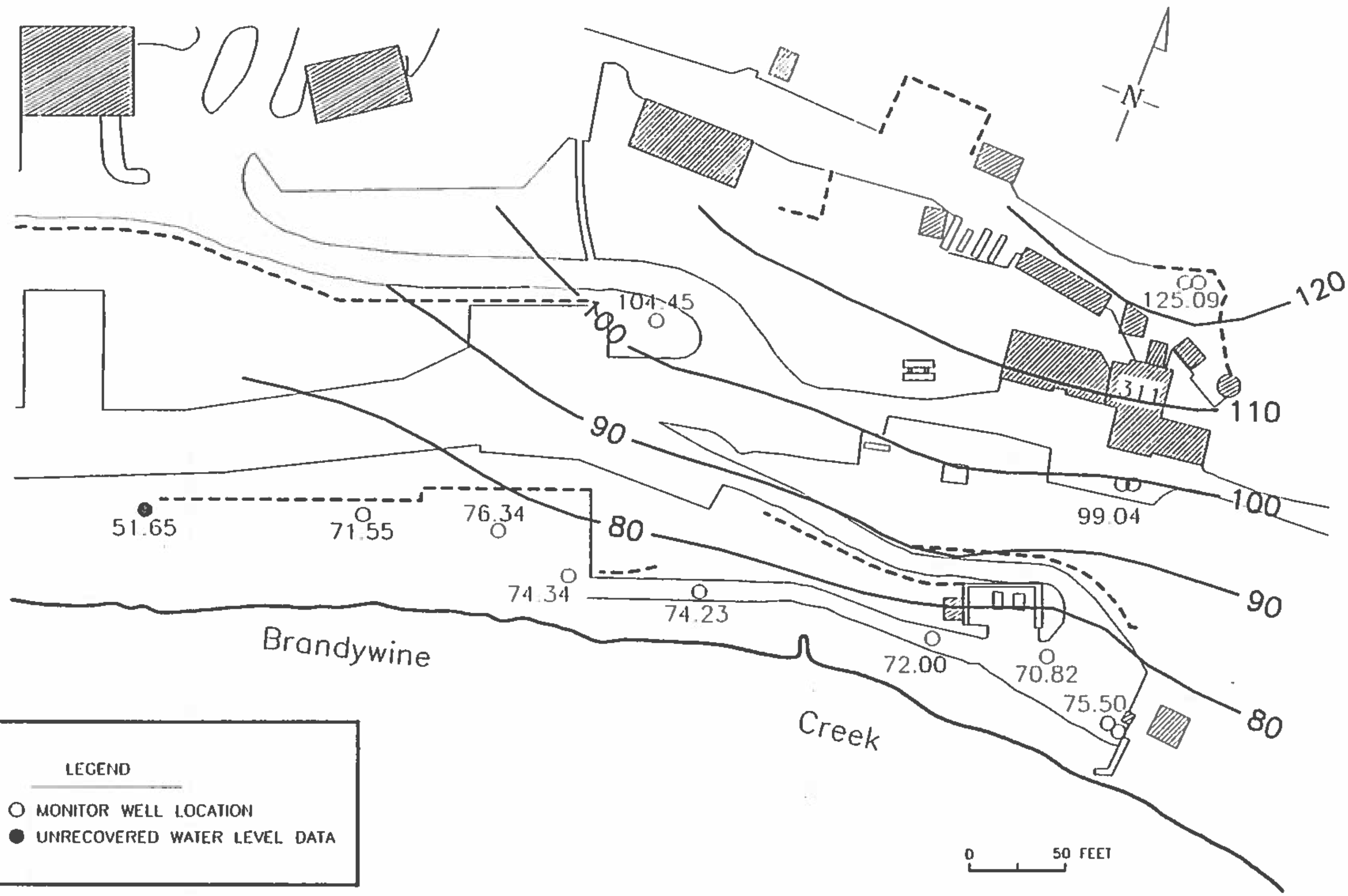

Figure 4.29. Potentiometric surface map - February 9, 1990, water-level survey.

GeoTrans / Tetra Tech
P8788-016/OA/26

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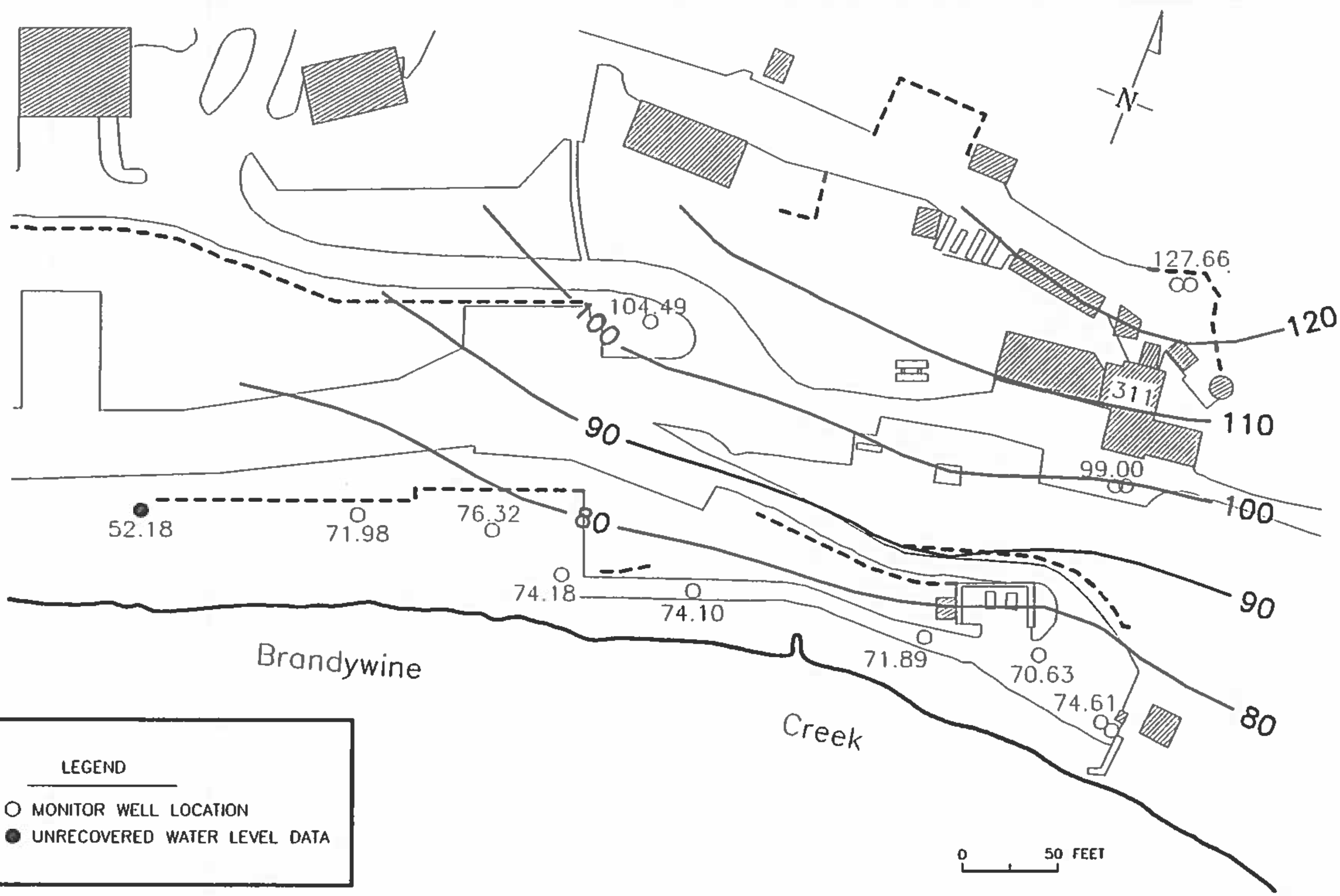

Figure 4.30. Potentiometric surface map - February 21, 1990, water-level survey.

GeoTrans / Tetra Tech
P8788-016/OA/27

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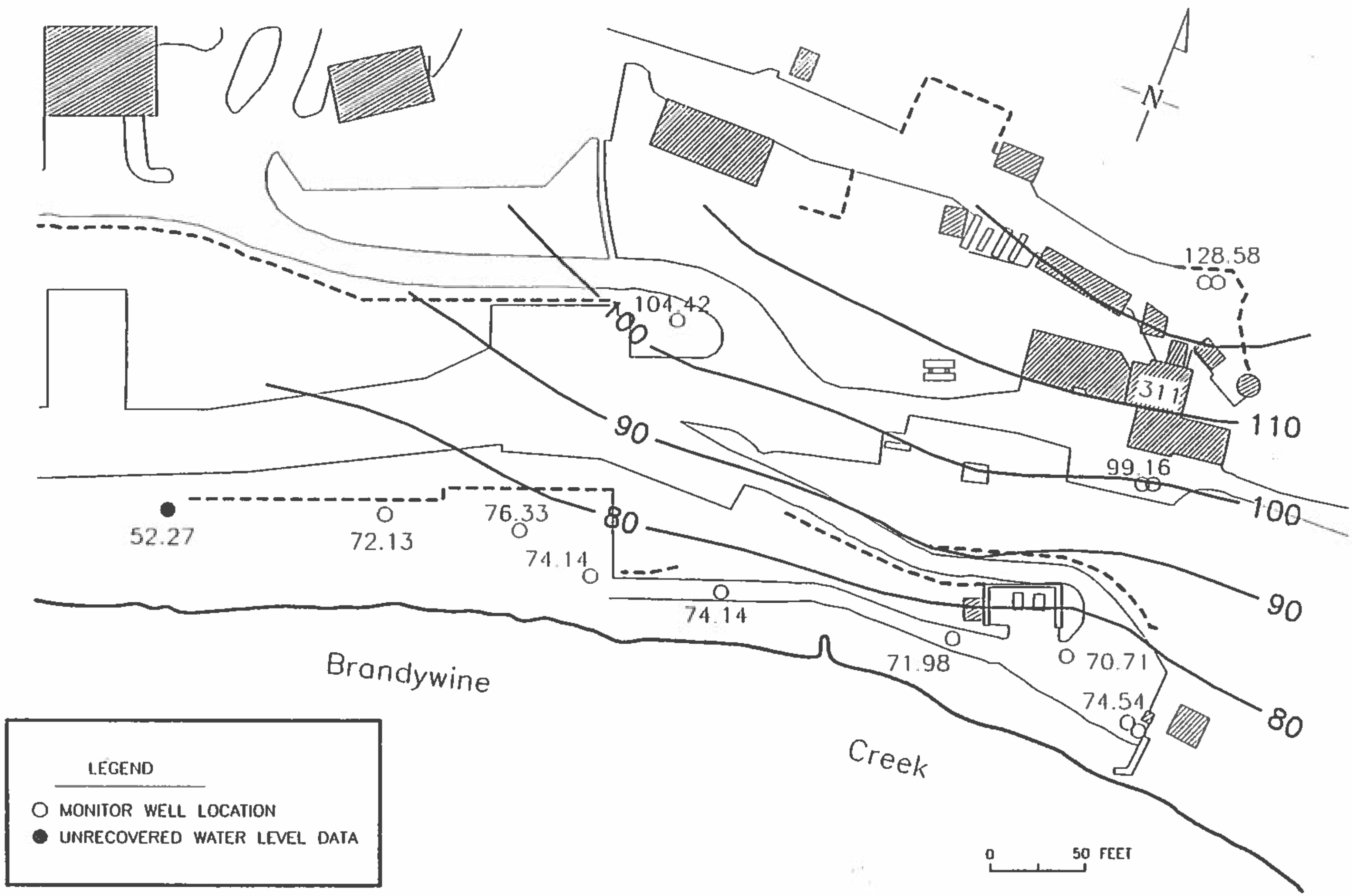

Figure 4.31. Potentiometric surface map - March 1, 1990, water-level survey.

GeoTrans / Tetra Tech
P8788-016/OA/28

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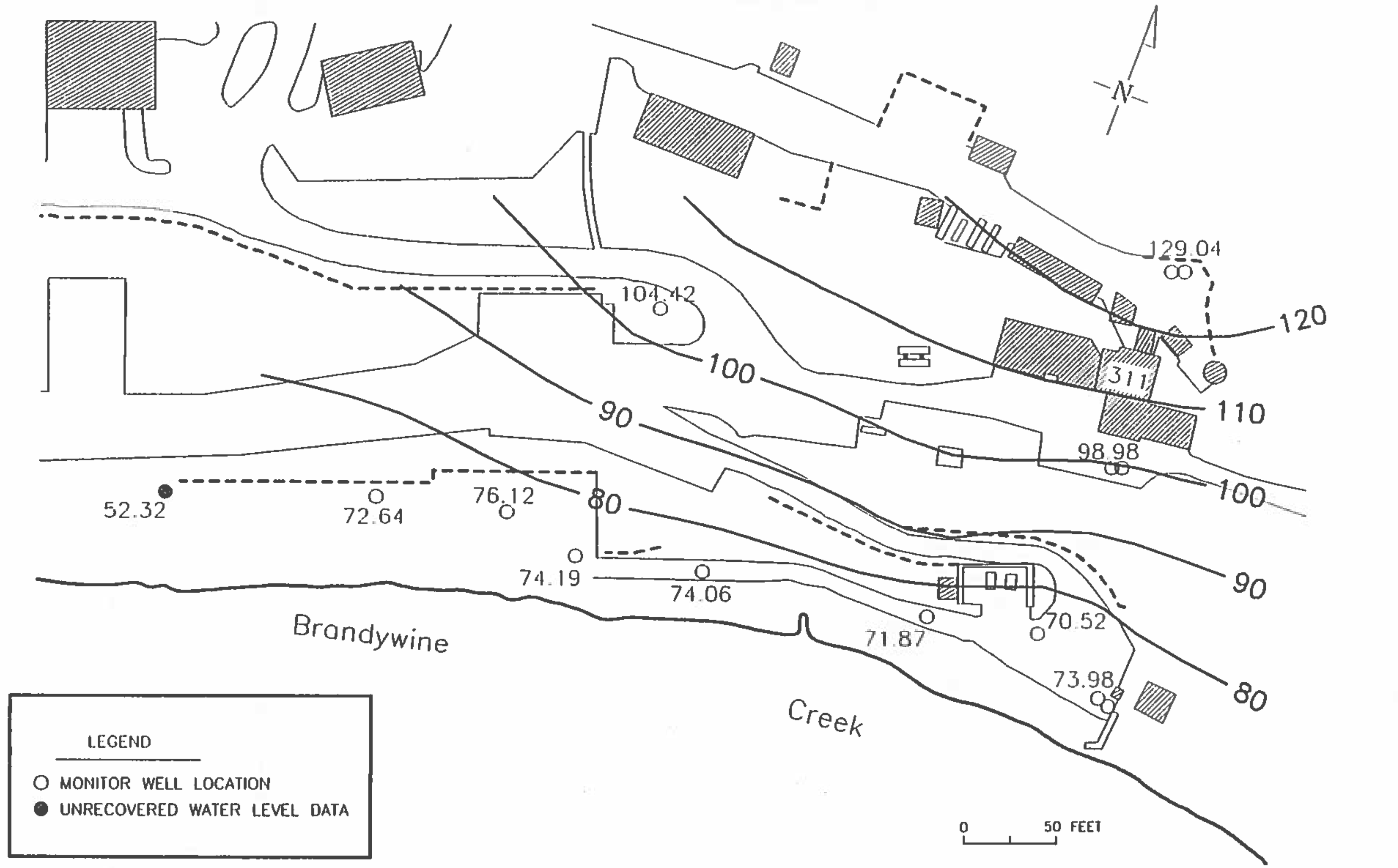

Figure 4.32. Potentiometric surface map - March 8, 1990, water-level survey.

GeoTrans / Tetra Tech
P8788-016/OA/29

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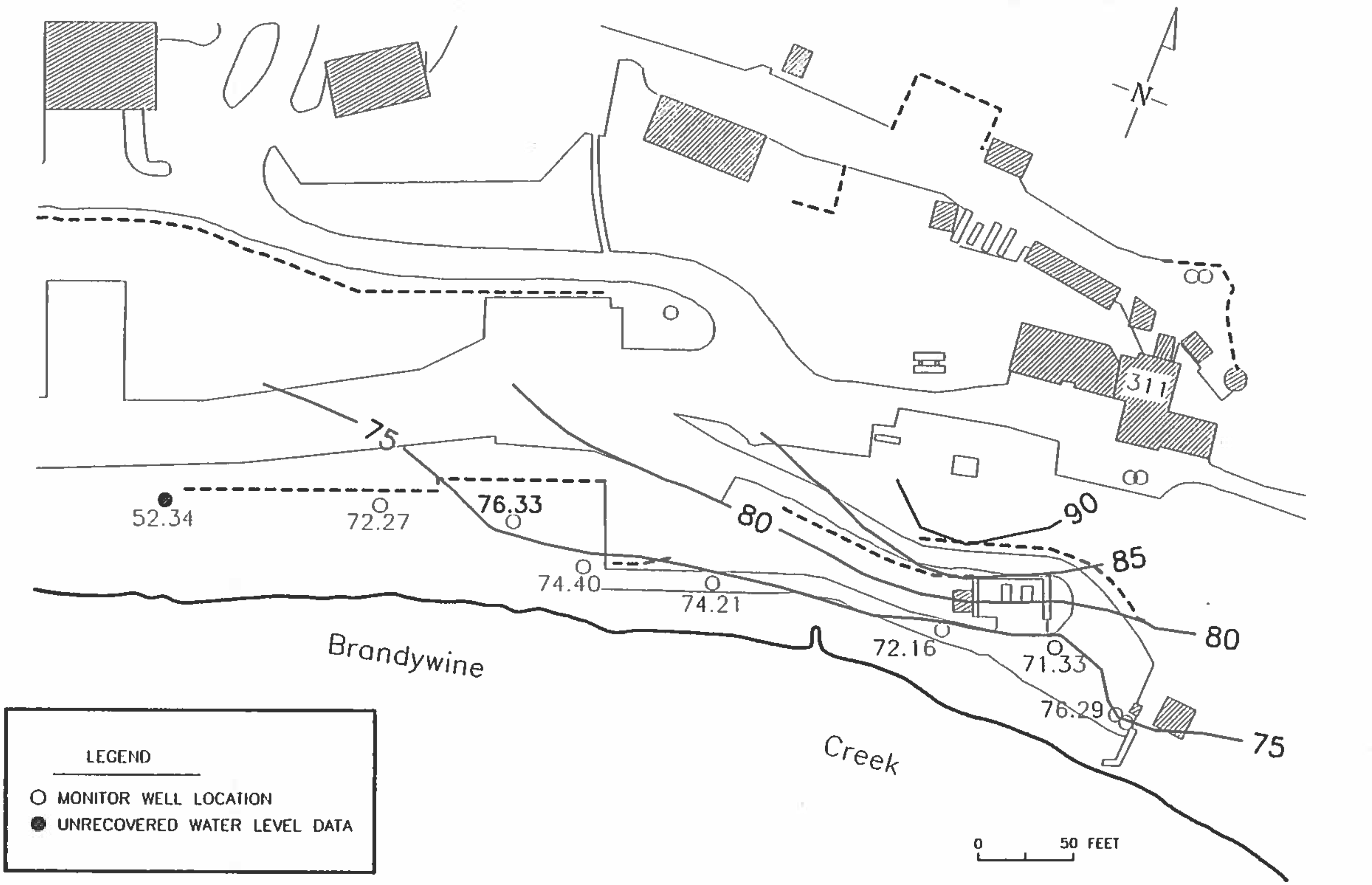

Figure 4.33. Potentiometric surface map - March 20, 1990, water-level survey.

GeoTrans / Tetra Tech
P8788-016/OA/30

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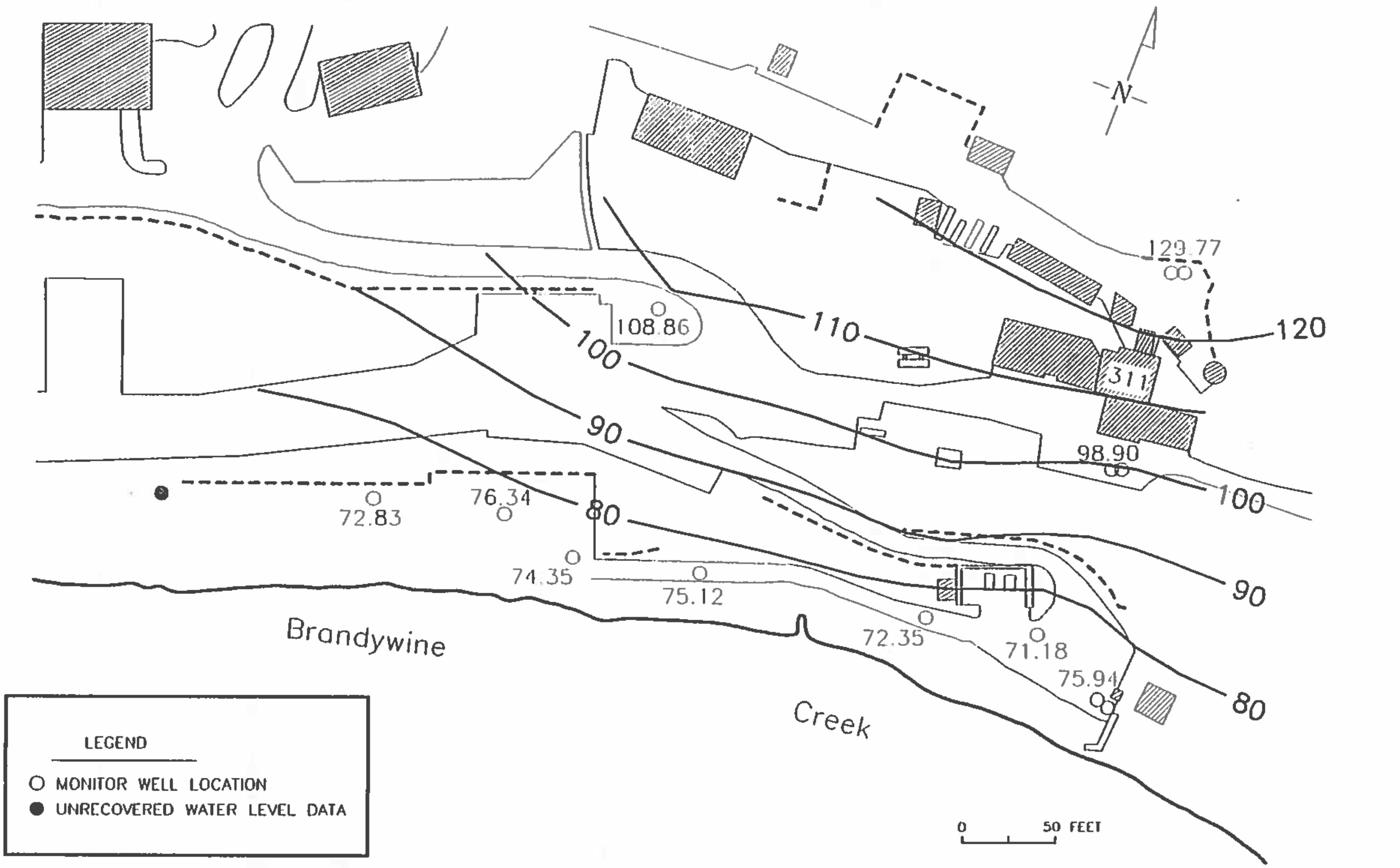

Figure 4.34. Potentiometric surface map - April 2, 1990, water-level survey.

GeoTrans / Tetra Tech
P8788-016/OA/31

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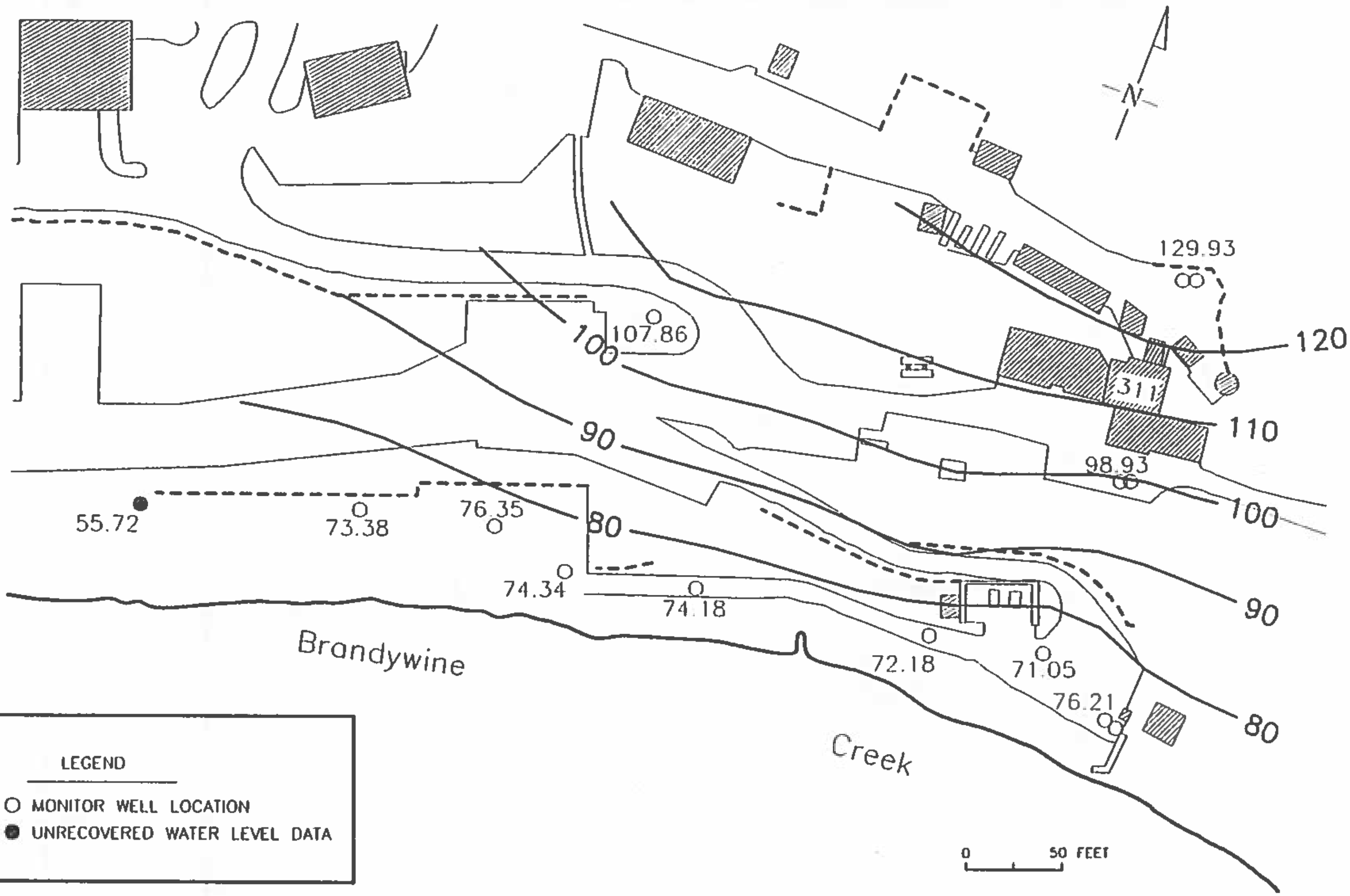

Figure 4.35. Potentiometric surface map - April 9, 1990, water-level survey.

GeoTrans / Tetra Tech
P8788-016/OA/32

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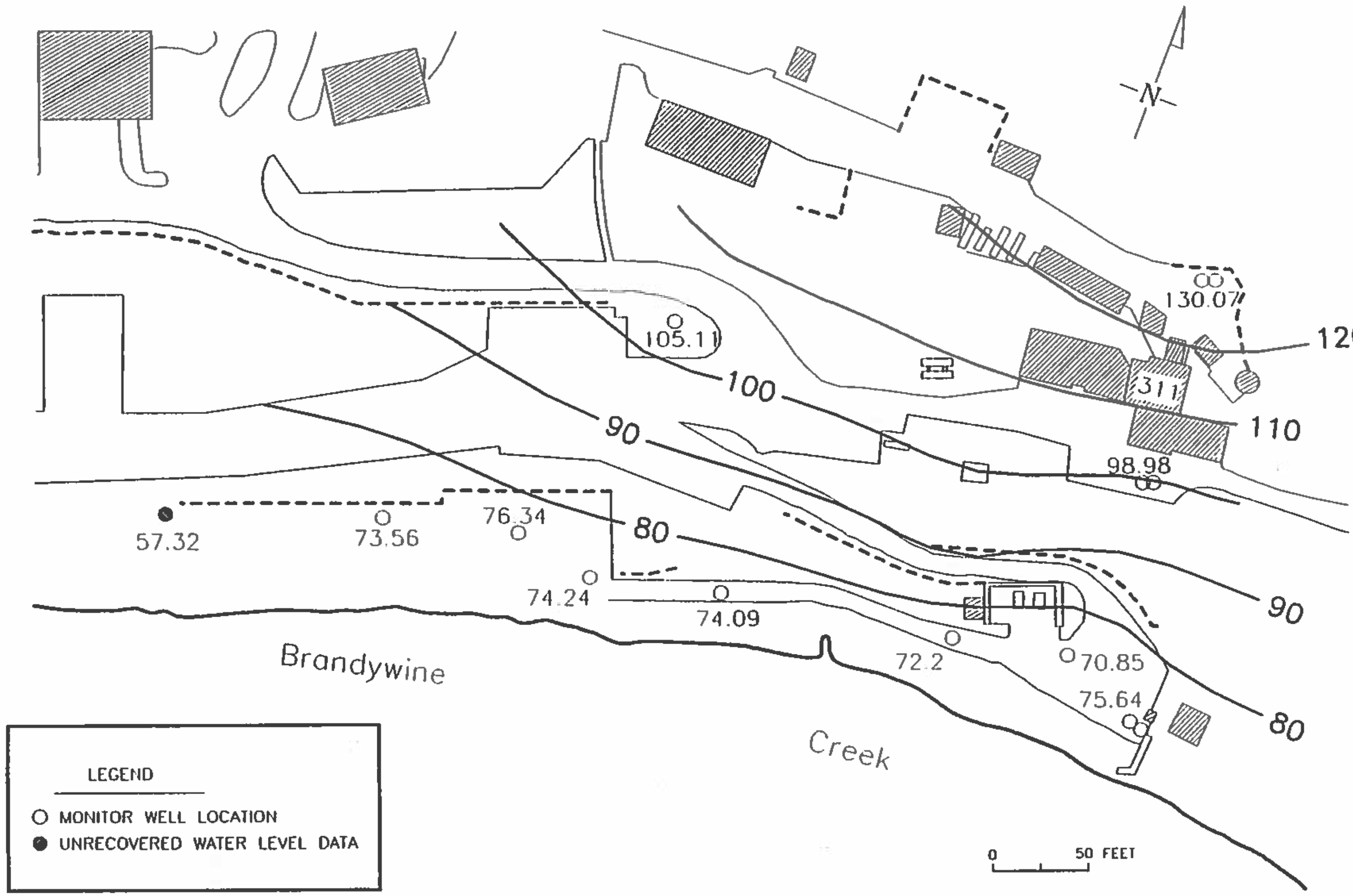

Figure 4.36. Potentiometric surface map - April 23, 1990, water-level survey.

GeoTrans / Tetra Tech
P8788-016/OA/33

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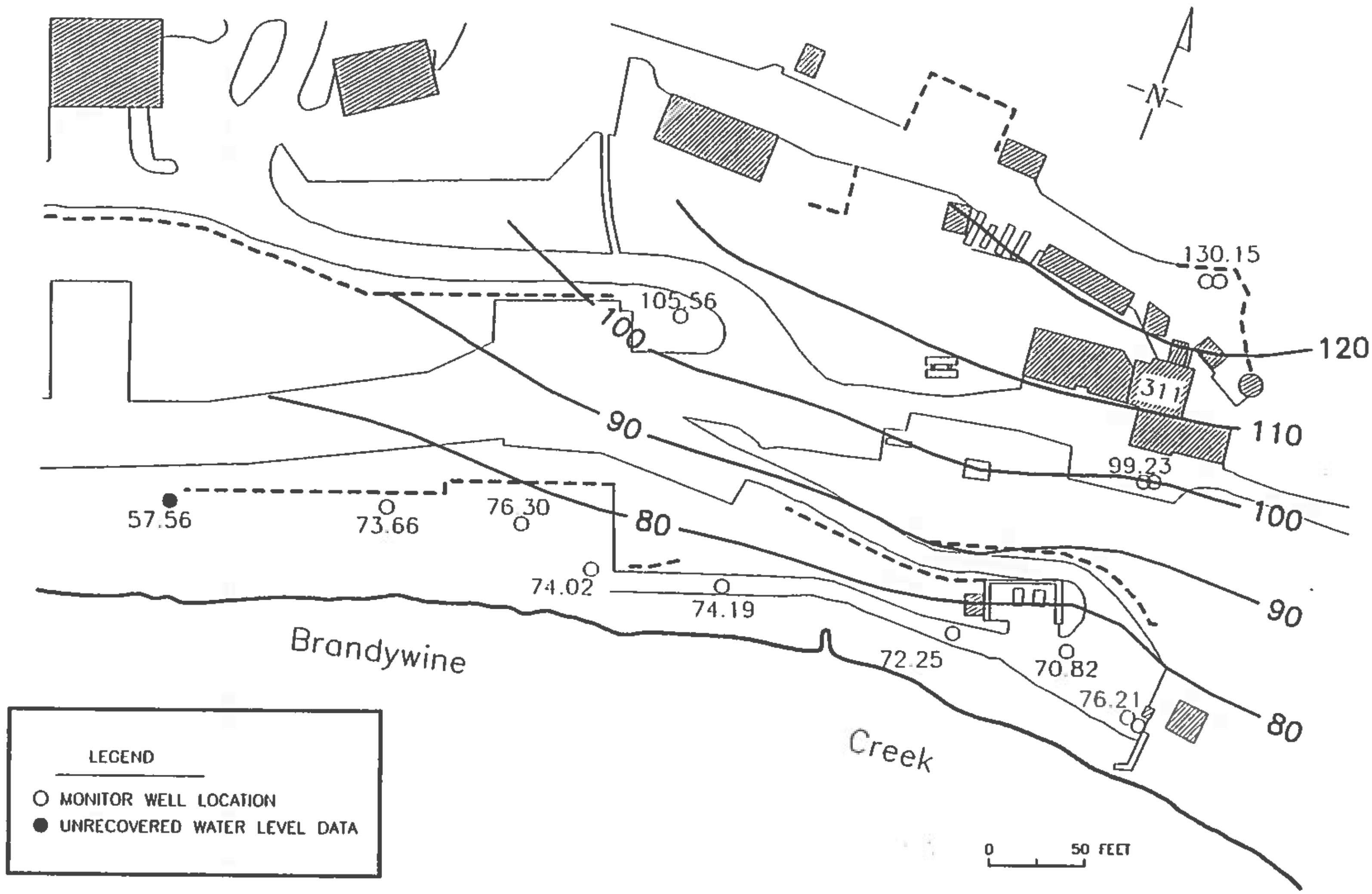

Figure 4.37. Potentiometric surface map - May 16, 1990, water-level survey.

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P8788-016/OA/34

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is not connected to the primary flow system. Attempts to include these data produced misleading gradient patterns.

The maps demonstrate that groundwater flow is toward Brandywine Creek. A slight bulge in the contours just north of MW-8 represents the area of groundwater discharge at two seeps. In general, the water table is five to ten feet below the ground surface.

4.5.2 Water-Quality Monitoring

4.5.2.1 Procedures

Two rounds of groundwater sampling were performed at the site. The first round of sampling was performed during the period January 11-12, 1990. The second round of sampling was performed during the period May 16-17, 1990. Two seeps were scheduled to be sampled at the same time as the well sampling. However, for both rounds there was insufficient flow present from these seeps for sampling purposes. Consequently, no seep samples were collected for chemical analyses.

The first round of groundwater sampling was conducted over a two-day period. On the first day (January 11, 1990), all existing and newly installed monitor wells were purged. Three well volumes were removed from each well, if possible. Many wells have extremely low yield and recovery; consequently, these wells were purged by pumping them dry several times. Because of the extremely low water yield of many of the wells, all wells were allowed to recover overnight prior to sampling. This overnight recovery period was required to allow a sufficient volume of water to collect into all of the wells and provide for consistency in the sampling of all wells.

Actual first round well sampling began on the second day (January 12, 1990). The wells were sampled in order of least suspected contamination to most suspected contamination. The sequence of well sampling was as follows: MW-1B, MW-1A, MW-11, MW-10, MW-9, MW-7, MW-6, MW-5, MW-8, MW-4, MW-3B, MW-3A, MW-2B, and MW-2A. All samples were collected according to the procedures provided in the approved RFI work plan, Attachment 4, Data Collection Quality Assurance Plan (July, 1989). A total of 17 samples were collected, including 14 groundwater samples, 1 duplicate sample, 1 equipment rinseate blank, and 1 trip blank.

The second round of sampling was conducted in the same manner as the first. As with the first round of sampling, no major problems were encountered during the second round of sampling. Field data recorded during sampling are provided in groundwater sampling logs (Appendix F).

4.5.2.2 Sample Analysis

Round 1 groundwater samples were analyzed for volatile organic compounds, metals and biphenyl/biphenyl oxides. Four samples were analyzed for the complete list of Appendix IX compounds. Round 2 groundwater samples were analyzed for volatile organic compounds only based on the results of Round 1 sampling, which showed little or no concentration of metals and semivolatiles. The samples from monitor wells were analyzed for the parameters shown in Table 4.10.

4.5.2.3 Results

The results of groundwater sampling are presented in Tables 4.11a and 4.11b. Data summary packages of the laboratory reports are provided in Appendix G. These packages were prepared by a quality assurance specialist, who performed validation on at least 10% of the samples in addition to compiling the data.

The majority of compounds detected in the groundwater were volatile organics. Analytes detected at greater than 1 ppm include 1,2,-dichloroethene, trichloroethene, and 1,1,2,2-tetrachloroethane. Additional VOCs detected include vinyl chloride, methylene chloride, acetone, tetrachloroethene, 1,1-dichloroethene, 1,1,1-trichloroethane, 1,1,2-trichloroethane, toluene, chlorobenzene, xylenes, chloroform, carbon tetrachloride, benzene, and ethyl benzene. These detections are consistent with the volatile organic compounds detected in the soils.

Comparison of duplicate samples collected at wells MW-2A and MW-3A show good reproducibility of results. The reported values are within 90% or better of the primary sample result. Comparison of Round 1 and Round 2 results shows no consistent trend in concentration changes at the well over time. Concentrations in Round 2 show a decrease at eight

Table 4.10. Groundwater sampling data.

Sample ID	Well ID	Round 1 Sampling Event Analyses	Round 2 Sampling Event Analyses
DEMW-1A	MW-1A	PP VOA[1], Metals[2], B/BO[3]	PP VOA
DEMW-1B	MW-1B	PP VOA, Metals, B/BO	PP VOA
DEMW-2A	MW-2A	PP VOA, Metals, B/BO	PP VOA
DEMW-2B	MW-2B	Appendix IX[4], B/BO	PP VOA
DEMW-3A	MW-3A	PP VOA, Metals, B/BO	PP VOA
DEMW-3B	MW-3B	Appendix IX, B/BO	PP VOA
DEMW-4	MW-4	PP VOA, Metals, B/BO	PP VOA
DEMW-5	MW-5	PP VOA, Metals, B/BO	PP VOA
DEMW-6	MW-6	PP VOA, Metals, B/BO	PP VOA
DEMW-7	MW-7	Appendix IX, B/BO	PP VOA
DEMW-8	MW-8	Appendix IX, B/BO	PP VOA
DEMW-9	MW-9	PP VOA, Metals, B/BO	PP VOA
DEMW-10	MW-10	PP VOA, Metals, B/BO	PP VOA
DEMW-11	MW-11	PP VOA, Metals, B/BO	PP VOA
DEMW-12	Duplicate of MW-3A	PP VOA, Metals, B/BO	PP VOA
DEMW-13	Duplicate of MW-2A	Not Analyzed	PP VOA
DEMW-FB	Field Blank	Collected after well MW-3A PP VOA, Metals, B/BO	PP VOA
DEMW-TB	Trip Blank	PP VOA	PP VOA

[1] PP VOA - priority pollutant volatile organic analyses
[2] Metals - priority pollutant inorganics
[3] B/BO - biphenyl/biphenyl oxide
[4] Appendix IX - analyses, including: volatile compounds; semivolatile compounds; organochlorine pesticide compounds; organophosphate pesticide compounds; herbicide compounds; dioxin compounds

Table 4.11a. Total volatile organic compounds and semivolatile compounds in groundwater.

Well ID	Open Interval (ft-ft)	Total VOCs (ppb) Round 1	Round 2	Total Semi-volatiles[1] (ppb) Round 1[2]	Biphenyl/ Biphenyl Oxide (ppb) Round 1[2]
MW-1A	10 - 39	4	ND	NA	ND
MW-1B	42 - 102	13	3	NA	ND
MW-2A	20 - 22	630	2151	NA	363
MW-2A	20 - 22	NA	2162	NA	ND
MW-2B	42 - 81	8904[1]	10060	35	ND
MW-3A	5 - 20	752	383	NA	ND
MW-3A	5 - 20	708	419	NA	ND
MW-3B	26 - 39	11090[1]	6803	16	ND
MW-4	13 - 21	47	166	NA	ND
MW-5	8 - 20	11	19	NA	ND
MW-6	8 - 20	373	714	NA	ND
MW-7	11 - 40	118[1]	27	9	ND
MW-8	8 - 19	1882[1]	1137	3.9	ND
MW-9	8 - 19	7	10	NA	ND
MW-10	9 - 42	13	8	NA	ND
MW-11	8 - 20	201	5	NA	ND

[1]Appendix IX list
[2]Samples collected under Round 2 were analyzed for VOCs only
ND - Not Detected
NA - Not Analyzed

Table 4.11b. Metals in groundwater.

	Concentration (ppb)										
Parameter	MW-1A	MW-1B	MW-2A	MW-3A	MW-4	MW-5	MW-6	MW-9	MW-10	MW-11	MW-12
Antimony	<60.0	<60.0	<60.0	<60.0	<60.0	<60.0	<60.0	<60.0	<60.0	<60.0	<60.0
Arsenic	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0
Beryllium	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0
Cadmium	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	<5.0
Chromium	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0
Copper	<25.0	<25.0	<25.0	<25.0	<25.0	<25.0	<25.0	<25.0	<25.0	<25.0	<25.0
Lead	< 3.0	< 3.0	< 3.0	< 3.0	< 3.0	< 3.0	< 3.0	< 3.0	< 3.0	3.75	< 3.0
Mercury	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Nickel	<40.0	<40.0	<40.0	<40.0	<40.0	<40.0	<40.0	<40.0	<40.0	<40.0	<40.0
Selenium	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0
Silver	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0
Tallium	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0
Zinc	<20.0	<20.0	<20.0	<20.0	53.5	<20.0	<20.0	<20.0	<20.0	<20.0	<20.0

wells and an increase at six wells. Note that this comparison is not exact because the Appendix IX volatiles list differs slightly from the Priority Pollutant volatiles list used in Round 2 for four samples.

Total semivolatile compounds analyzed under the Appendix IX list were detected in only minor quantities. Concentrations ranged from 3.9-35 ppb. Biphenyls were detected only in MW-2A at a concentration of 363 ppb.

No cyanides or dioxins/furans were reported for any sample site. Concentrations of pesticides, reported in three samples (MW-8, MW-3B, and MW-7), ranged from 0.04-0.06 ppb. Herbicides were reported in one sample only (MW-8) at a total concentration of 0.54 ppb. The sampling results are consistent with the historic data. The highest concentrations are observed at MW-2B and MW-3B, south of the incinerator area. It should be noted that concentrations at MW-2A historically have been significantly higher than reported here. This is most likely due to the change in open interval from twenty feet to two feet caused by in-filling of the well with grout during construction of MW-2B.

4.6 SURFACE WATER SAMPLING

4.6.1 Procedures

One round of surface water sampling was performed on January 12, 1990. Four surface water stations were sampled. Sample locations are shown in Figure 4.38. All samples were collected according to the procedures provided in the approved RFI work plan, Attachment 4, Data Collection Quality Assurance Plan (July 1989). A total of seven samples were collected, including four surface water samples, one duplicate sample, one equipment rinseate blank, and one trip blank. The surface water samples were analyzed for the parameters shown in Table 4.12.

4.6.2 Results

The results of surface water sampling are presented in Table 4.13a and 4.13b. For all samples, the reported VOC results represent

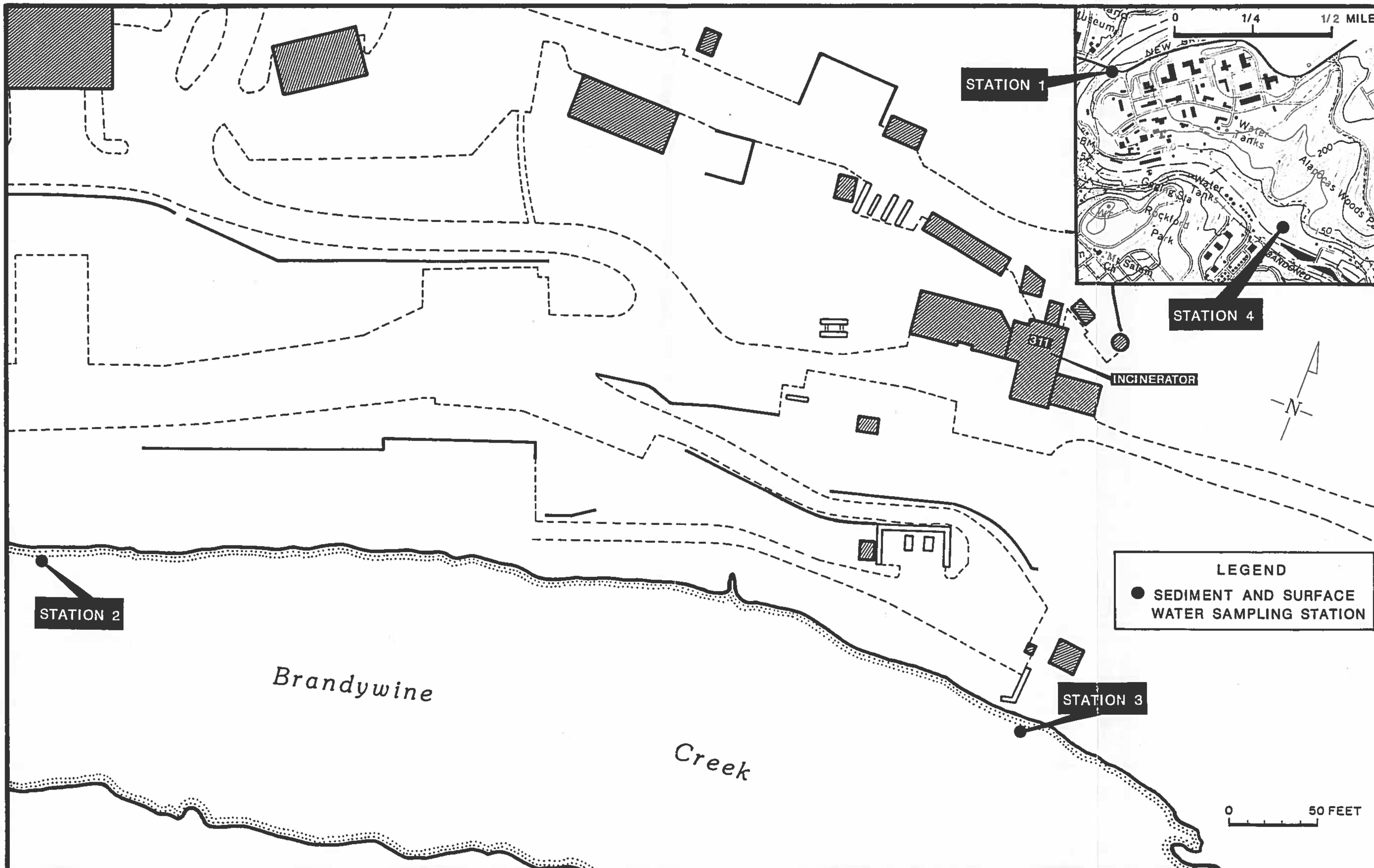

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Figure 4.38. Location of sediment and surface water sampling locations.

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Table 4.12. Surface water sampling data.

Sampled ID	Location	Analyses
DESW-1	SW-1	PP VOA[1], Metals[2], B/BO[3]
DESW-1	SW-2	PP VOA, Metals, B/BO
DESW-3	SW-3	PP VOA, Metals, B/BO
DESW-4	SW-4	PP VOA, Metals, B/BO
DESW-5	SW-3	PP VOA, Metals, B/BO
DESW-FB	Field Blank	PP VOA, Metals, B/BO
DESW-TB	Trip Blank	PP VOA

[1]PP VOA - priority pollutant volatile organic analyses
[2]Metals - priority pollutant inorganics
[3]B/BO - biphenyl/biphenyl oxide

Table 4.13a. Surface water sampling results for total VOCs and biphenyls.

Sample No.	Sample Date	Total VOC (ppb)	Biphenyl/Biphenyl Oxide (ppb)
DESW-1	01/12/90	5	ND
DESW-2	01/12/90	5	ND
DESW-3	01/12/90	5	ND
DESW-4	01/12/90	5	ND
DESW-5	01/12/90	6	ND

ND - Not Detected
NOTE: Refer to Figure 4.38 for location of sample.

Table 4.13b. Metals in surface water.

Parameter	Concentration (ppm)				
	DESW-1	DESW-2	DESW-3	DESW-4	DESW-5
Antimony	<60.0	<60.0	<60.0	<60.0	<60.0
Arsenic	<10.0	<10.0	<10.0	<10.0	<10.0
Beryllium	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0
Cadmium	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0
Chromium	<10.0	<10.0	<10.0	<10.0	<10.0
Copper	<25.0	<25.0	<25.0	<25.0	<25.0
Lead	< 3.0	< 3.0	< 3.0	< 3.0	< 3.0
Mercury	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Nickel	<40.0	<40.0	<40.0	<40.0	<40.0
Selenium	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0
Silver	<10.0	<10.0	<10.0	<10.0	<10.0
Tallium	<10.0	<10.0	<10.0	<10.0	<10.0
Zinc	<20.0	26.8	<20.0	<20.0	<20.0

methylene chloride, which was the only analyte detected. Methylene chloride was also detected in the blank for these samples. Therefore, it is assumed that no detectable VOCs were actually present in the sample. Biphenyls also were not detected in any samples.

4.7 SEDIMENT SAMPLING

4.7.1 Procedures

One round of sediment sampling was performed; however, samples were collected on two separate dates (January 12, 1990 and March 16, 1990). Initially, complete sediment sampling was performed on January 12, 1990. However, the laboratory exceeded holding times for analysis of the samples for biphenyl/biphenyl oxide. Consequently, additional samples were collected on March 16, 1990, and analyzed for biphenyl/biphenyl oxide.

Four sediment stations (located at the surface water sample stations) were sampled. All sediment samples were collected according to the procedures provided in the approved RFI work plan, Attachment 4, Data Collection Quality Assurance Plan (July, 1989). A total of seven samples were collected, including four sediment samples, one duplicate sample, one equipment rinseate blank, and one trip blank. Sediment samples were analyzed for the parameters shown in Table 4.14.

With the exception of the laboratory problem previously stated, no major problems were encountered during sediment sampling.

4.7.2 Results

The results of river sediment sampling are presented in Table 4.15a and 4.15b. For samples from Station 3 (DESD-3 and DESD-5), the reported VOC results represent three detected analytes: (1) trans-1,2-dichloroethene, (2) trichloroethylene, and (3) tetrachloroethylene. For the sample at Station 4 (DESD-4), the only detected analyte was toluene. The fact that toluene is present downstream from the site but does not occur in sediments at the site suggests that another source for this compound exists downstream of the Experimental Station. However, the Experimental Station is a likely source for the VOAs

Table 4.14. Sediment sampling data.

Sampled ID	Location	Analyses
DESD-1	SW-1	PP VOA[1], Metals[1], B/BO[2]
DESD-2	SW-2	PP VOA, Metals, B/BO
DESD-3	SW-3	PP VOA, Metals, B/BO
DESD-4	SW-4	PP VOA, Metals, B/BO
DESD-5	SW-3	PP VOA, Metals, B/BO
DESD-FB	Field Blank	PP VOA, Metals, B/BO
DESD-TB	Trip Blank	PP VOA

[1] Sampled 1/12/90
[2] Samples 3/16/90

Table 4.15a. Sediment sampling results for total VOCs and biphenyls.

Sample No.	Total VOC (ppb)[1]	Biphenyl/Biphenyl Oxide (ppb)[2]
DESD-1	ND	ND
DESD-2	ND	16
DESD-3	422	ND
DESD-4	21	ND
DESD-5	558	26

[1] VOC samples collected January 12, 1990
[2] Biphenyl/Biphenyl Oxide samples collected March 16, 1990
ND - Not Detected
NOTE: Refer to Figure 4.36 for location of samples.

Table 4.15b. Metals in sediment samples.

Parameter	Concentration (ppm)				
	DESD-1	DESD-2	DESD-3	DESD-4	DESD-5
Antimony	<8.82	<7.79	<8.57	<8.70	<7.32
Arsenic	<1.47	4.12	1.85	<1.45	2.09
Beryllium	<0.74	8.42	<0.71	<0.73	0.566
Cadmium	<0.74	53.1	<0.71	<0.73	<0.61
Chromium	22.8	207	22.0	18.8	26.3
Copper	11.1	52.4	33.2	25.0	32.3
Lead	3.82	46.7	49.0	85.4	39.9
Mercury	<0.15	3.05	2.04	<0.14	1.21
Nickel	14.9	42.5	17.0	15.6	15.5
Selenium	<0.72	<0.65	<0.71	<0.72	<0.61
Silver	<1.47	<1.30	<1.42	<1.45	<1.22
Tallium	<1.47	<1.30	<1.42	<1.45	<1.22
Zinc	49.8	396	134	121	170

detected at Station 3 based on the high concentration of VOAs present in the soil at soil boring C, located upslope from Station 3.

Biphenyls were detected in one sample from Station 3 but not its duplicate. This is a reflection of the inherent heterogeneity in the sediment material itself. Biphenyls were also detected at Station 2 upstream from Station 3.

5 CHARACTERIZATION OF ENVIRONMENTAL SETTING

5.1 GEOLOGIC SETTING

The geologic setting in the vicinity of the site is described in the literature as consisting of meta-igneous rocks of the Wilmington Complex. The formation is primarily characterized as a hard, banded gneiss with narrow, widely-spaced joints. Locally, the formation is known as the "Brandywine Blue Granite". The major structural features in the area trend northeast and northwest. Section 4.1.2 provides a more detailed discussion of the regional structural geology.

The site itself is located along the banks of the Brandywine Creek. The area of investigation is situated along a steep slope with numerous bedrock outcrops. The bedrock surface slopes toward the river as shown in Figure 5.1. Cut and fill activities over several decades have modified the topography. The bedrock is overlain by a mixture of colluvium and fill material. The thickness of the overburden varies across the site and a range of 2-18 feet was observed from subsurface investigations for the RFI. A schematic cross-section of the site is shown in Figure 5.2.

Geologic logs prepared from well and test pit installations show that the site geology is consistent with the regional setting. At nearly all locations encountered, the rocks consist of a hard, variably-fracture gneiss overlain by heterogenous, unconsolidated materials. Two exceptions to this description are the MW-3A and MW-3B locations. At these sites, the bedrock is not encountered except as broken, weathered material. The unconsolidated material that extends the length of the boring appears to be in-situ, natural material. It appears that these wells intersect sand-filled, vertical fracture zones.

The overburden is generally a sandy-silt matrix with clay, cobbles, and boulders. Different types of fill materials are present, often in vertically discrete, but horizontally discontinuous zones.

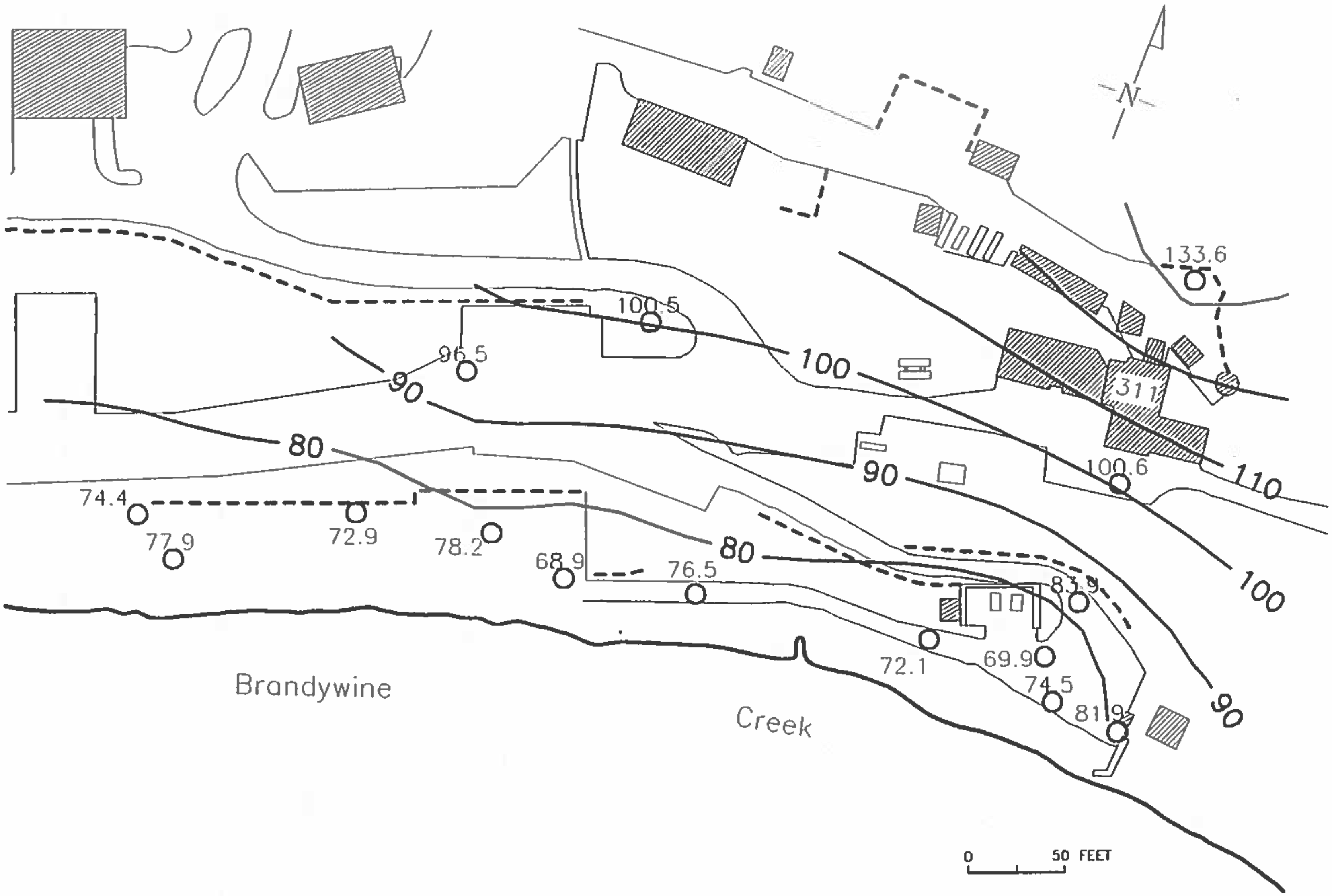

Figure 5.1. Elevation of the bedrock surface.

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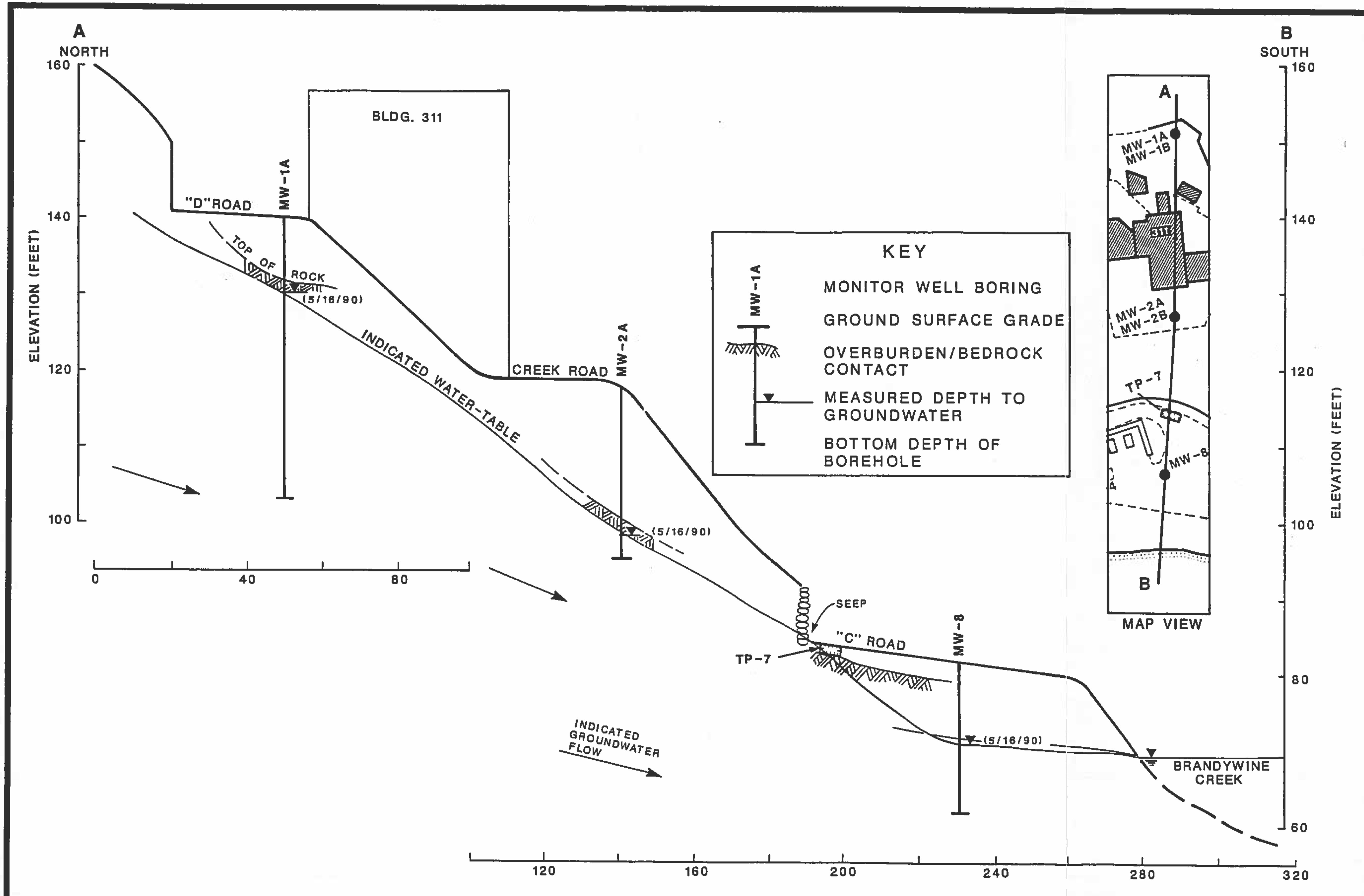

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Figure 5.2. Schematic cross-section showing groundwater and bedrock elevations.

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Typical example descriptions include:

- Ash.
- Fill with cobbles, boulders and clay.
- Fill with glass, bricks, cinders.

Color of the fill ranges from orange to grey to brown.

5.2 HYDROGEOLOGIC SETTING

Regionally, the Wilmington Complex has low secondary permeability and well yields are generally low. Woodruff (1981) reports that "the yield of the average house well is about 1 gpm and dry holes are fairly common." The Brandywine Creek represents a major discharge point for the bedrock aquifer in the vicinity of the site.

The hydrogeologic setting at the site is characterized by a saturated, low-permeability bedrock aquifer and a variably-saturated zone in the overburden. Groundwater flow is primarily through fractures and along the overburden/bedrock interface. Permeability in the bedrock aquifer appears to decrease with depth as evidenced by the slow recovery rate observed in deep wells MW-1B and MW-2B during aquifer testing. Additionally, tracer test results showed little or no movement of the Fluorescein dye from well MW-2B.

Aquifer test results for slug tests and pumping tests demonstrate the variability in hydraulic properties over the relatively small area of investigation. Estimated hydraulic conductivity values range over five orders of magnitude.

Numerous water-level surveys demonstrate that the groundwater flow direction is consistently toward Brandywine Creek in all sections of the area of investigation. In fracture flow, discrete flow paths may turn in many directions before reaching the main discharge boundary. However, based on the structural evidence presented in Section 4.1, flow paths at the site should trend primarily northwest-southeast toward the river. This is supported by pumping test results and tracer test results that show progressively less hydraulic connection between MW-2A and other site wells with increasing distance to the southwest.

For example, good hydraulic connection exists between well MW-2A and wells MW-3A, MW-3B; moderate connection is observed between MW-2A and MW-8 and MW-4; and no connection is observed between MW-2A and the remaining wells. The occurrence of two seeps behind storage area 23, where bedrock is close to ground surface, is evidence that some groundwater travels along the overburden/bedrock interface. The detection of Rhodamine dye in the seeps during the tracer tests indicates a hydraulic connection to the aquifer in the vicinity of MW-2A.

All together the data suggest that groundwater in the vicinity of the incinerator discharges relatively quickly and directly to the river along a northwest/southeast-trending zone. Discrete groundwater flow paths in the area west of the incinerator can not be identified because of the lack of observable responses during pumping tests and tracer tests.

Any groundwater discharged from the study area will mix with and be diluted by the creek water. Table 5.1 is a recent report of the flow in Brandywine Creek nearby and upstream of the site. The 42 year record indicates that the average flow has been 477 cubic feet per second. The minimum daily discharge during the period of record was 50 cubic feet per second.

5.3 GROUNDWATER DISCHARGE TO BRANDYWINE CREEK

The geometry of the water bearing zone and available groundwater and surface water elevation data clearly demonstrate that groundwater below the study area discharges to Brandywine Creek. On the other hand, the quantity of groundwater flow is not so readily evaluated. Typical of fractured and low permeability hydrogeologic units, the aquifer testing showed a high degree of heterogeneity (i.e. transmissivity values ranging over 5 orders of magnitude). The extreme heterogeneity makes direct estimation of groundwater discharge difficult.

The quantity of groundwater discharge to Brandywine Creek is critical element in the feasibility studies to be done under the Consent Order, governing the site. In particular, the groundwater

Table 5.1. Discharge record for Brandywine Creek from USGS gauging station 0.2 miles downstream of Rising Sun Bridge.

DELAWARE RIVER BASIN

01481500 BRANDYWINE CREEK AT WILMINGTON, DE

LOCATION.--Lat 39°46'08", long 75°34'25", New Castle County, Hydrologic Unit 02040205, on right bank in Rockford Park, 0.2 mi downstream from Rising Sun Bridge, in Wilmington, and 4.2 mi upstream from mouth.

DRAINAGE AREA.--314 mi^2.

PERIOD OF RECORD.--October 1946 to current year. Prior to December 1946 monthly discharge only, published in WSP 1302.

REVISED RECORDS.--WSP 1432: 1948, 1950.

GAGE.--Water-stage recorder and concrete control. Datum of gage is 88.23 ft above National Geodetic Vertical Datum of 1929.

REMARKS.--Records good except those for estimated daily discharges (ice effect), which are fair. Some diurnal fluctuation at low flow caused by mills upstream from station. Flow regulated since November 1973 by Marsh Creek Reservoir, capacity 7,220,000,000 gal, about 27 mi upstream. No diversion just upstream from station by plant of E. I. du Pont de Nemours & Co. since June 13, 1960. Several measurements of water temperature were made during the year. Water-quality records for some prior periods have been collected at this location.

AVERAGE DISCHARGE.--42 years, 477 ft^3/s, 20.63 in/yr, adjusted for storage since November 1973.

EXTREMES FOR PERIOD OF RECORD.--Maximum discharge, 29,000 ft^3/s, June 23, 1972, gage height, 15.49 ft, from rating curve extended above 18,000 ft^3/s; minimum discharge, about 30 ft^3/s, Dec. 25, 1948, during period of ice effect; minimum daily discharge, 50 ft^3/s, Aug. 23, 24, 1957.

EXTREMES FOR CURRENT YEAR.--Peak discharges greater than base discharge of 4,000 ft^3/s and maximum (*):

Date	Time	Discharge (ft^3/s)	Gage height (ft)	Date	Time	Discharge (ft^3/s)	Gage height (ft)
Nov. 30	1415	5,690	8.07	Jan. 20	1700	4,760	7.51
Jan. 20	1315	(a)	*8.47	May 19	2245	*5,840	8.20

a Ice jam

Minimum discharge, 89 ft^3/s, Oct. 26, gage height, 2.38 ft; minimum daily discharge, 119 ft^3/s, Aug. 17.

DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1987 TO SEPTEMBER 1988
MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	235	185	1040	344	793	495	330	392	444	134	280	[illegible]
2	163	181	555	331	1500	468	352	363	481	181	228	175
3	216	174	455	285	1130	466	349	350	419	177	204	165
4	307	168	429	326	817	614	361	366	412	172	200	483
5	202	160	397	*290	785	1180	370	443	405	159	191	1030
6	172	153	363	297	498	606	330	1160	384	152	182	330
7	212	160	348	287	408	539	609	915	370	157	190	231
8	203	160	311	257	484	450	721	585	364	155	175	193
9	171	170	288	301	444	433	451	517	383	161	151	153
10	164	243	280	264	428	431	394	481	385	153	156	169
11	164	952	285	229	417	399	372	1250	353	156	147	162
12	167	428	268	241	1790	393	363	695	339	153	150	151
13	165	376	257	259	1060	396	358	537	333	165	145	197
14	160	738	243	246	550	387	353	502	323	148	136	187
15	160	295	335	246	569	378	351	467	315	139	132	152
16	161	271	516	247	2040	359	364	428	310	128	121	137
17	157	247	330	238	1030	361	355	444	308	170	119	133
18	162	248	289	315	691	356	385	693	308	752	141	163
19	161	243	276	544	708	359	477	4250	299	366	129	159
20	167	214	308	*2430	2320	356	401	2810	294	1150	168	146
21	194	200	376	1330	977	350	379	1310	283	663	203	141
22	225	184	300	658	695	339	368	1040	287	1940	168	133
23	183	194	293	460	651	340	364	1090	255	750	134	128
24	174	207	283	444	629	341	393	1230	238	1290	518	145
25	174	206	283	457	563	345	352	823	229	584	346	148
26	158	205	320	512	530	525	327	666	225	430	172	152
27	192	202	309	400	529	804	335	583	217	830	147	141
28	706	203	288	365	537	479	972	548	204	973	140	132
29	330	500	294	413	512	389	486	520	202	599	427	127
30	225	4500	255	419	---	371	427	494	195	348	696	124
31	159	---	272	429	---	360	---	465	---	305	267	---
TOTAL	6369	11967	10846	13864	24115	14173	12495	26466	9544	14032	6641	6108
MEAN	205	399	350	447	832	457	416	854	318	453	214	204
MAX	706	4500	1040	2430	2320	1180	972	4260	481	1940	696	1030
MIN	157	153	243	229	408	339	327	350	195	128	119	124
[illegible]†	-0.5	+11.6	-10.9	-23.1	+5.4	+19.2	0	-1.0	-1.2	+5.9	-4.6	-2.9
MEAN#	206	411	339	424	837	476	416	853	317	459	209	201
CFSM#	0.65	1.31	1.08	1.35	2.67	1.52	1.32	2.72	1.01	1.46	0.67	0.64
IN#	0.76	1.46	1.24	1.56	2.87	1.75	1.48	3.13	1.13	1.68	0.77	0.71

CAL YR 1987 TOTAL 141733 MEAN 388 MAX 4500 MIN 92 MEAN# 390 CFSM# 1.24 IN# 16.86
WTR YR 1988 TOTAL 156622 MEAN 428 MAX 4500 MIN 119 MEAN# 428 CFSM# 1.36 IN# 18.54

* Estimated

† Change in contents in Marsh Creek Reservoir, equivalent in cubic feet per second, provided by Pennsylvania Department of Environmental Resources.

Adjusted for change in reservoir contents.

discharge together with contaminant concentrations in wells will be used to estimate mass loadings of contaminants to the creek. Because the creek is the primary receptor of potentially contaminated groundwater, loadings to the creek are critical to both the need and extent of remedy.

The analysis that follows was intended to:

(1) provide a best estimate of groundwater discharge to Brandywine Creek along the reach of the study area;

(2) provide a measure of the confidence in the discharge estimate; and

(3) quantify variations in discharge at different locations along the reach of the creek in the study area.

A related issue was the significance of the high permeability determined for one the wells (i.e., MW-9). More specifically; could a small high permeability zone yield large groundwater discharges?

5.3.1 Flow Analysis Approach

A stochastic groundwater flow analysis was used to evaluate groundwater discharge to the creek. The stochastic approach was chosen because of the flow system complexity. The approach was selected to provide not only discharge estimates but a basis for assessing confidence in the estimate.

The analysis procedure consisted of the following steps:

(1) The transmissivity data from the slug tests were interpolated using a kriging program (AKRIP). The results included estimates of the mean and variance of log transmissivity on ten foot centers over the study area.

(2) A finite-element grid was designed with element centers corresponding to points at which transmissivity was estimated using the kriging program.

(3) The finite-element program SEFTRAN was used to calculate head values using transmissivity estimates selected for each element from a log normal distribution using the kriged values for mean and variance.

(4) The calculated head values were compared with observed groundwater elevations. The comparison showed that the lower transmissivity estimates were not representative at the element scale of 10 feet by 10 feet.

(5) Several additional flow simulations were performed, successively raising the lower bound on transmissivity until a reasonable comparison between observed heads and computed heads were achieved. The minimum transmissivity value was 2.4 ft^2 per day.

(6) A series of 50 simulations were run. Each simulation corresponded to an independent realization of the kriged transmissivity data. The discharge rates for each node point along Brandywine creek were computed and summarized. These results provide estimates of groundwater discharge and variability to Brandywine Creek.

The computer program AKRIP was used to interpolate the transmissivity data collected from the slug testing. The program is described by Kafritsas and Bras (1981). The method used to provide the interpolation is called kriging and is based on the theory of intrinsic random functions of order k (IRF-K). Kriging not only provides estimates of transmissivity but also provides a measure of the estimate error or variance.

Because measured transmissivities varied over five orders of magnitude, the log of the transitivity was kriged. Thus, the mean and variance estimates are in terms of log transmissivity. The transmissivity data used as input are provided in Table 5.2. The results of kriging analysis are shown in Plates 5 and 6. Plate 5 is a contour map of the $\log_{10}T$ estimates and Plate 6 is the estimate of the variance of $\log_{10}T$. Estimates were obtained on a grid at 10 foot centers corresponding to the center of the elements used for the flow simulations using SEFTRAN.

SEFTRAN was used to simulate the groundwater flow over the study area. SEFTRAN is a two-dimensional, finite-element program (GeoTrans, 1988). To use the program, a computational grid (finite-element grid) is constructed over the area of interest (see Plate 7). For general, steady-state simulations it is necessary to specify transmissivity, recharge rates, pumping rates, and boundary conditions. For the simulations performed here no pumping or recharge was specified.

Table 5.2. Data used in AKRIP: coordinates are in feet and transmissivity is in ft²/d.

Well No.	X Coordinate	Y Coordinate	$Log_{10}T$
1	626	359	-2.82
2	586	251	1.62
3	585	122	0.85
4	487	171	0.28
5	365	195	1.66
6	259	227	0.45
7	187	238	-2.82
8	547	161	0.11
9	296	203	2.32
10	73	237	-3.22
11	341	338	1.08

Recharge in the study area is small compared to the flow from upgradient because of the steep slopes and pavement and buildings. Thus, the boundary conditions and transmissivity controlled the simulated flow field.

The boundary conditions used in the model are illustrated in Figure 5.3. While the creek can be considered a natural constant head boundary, the specification of constant heads on the northern boundary was done to limit the size of the computational grid. This would normally overconstrain the solution and be undesirable. For the present stochastic analysis however, interest is focused on discharge to the creek and the limiting assumption is not significant.

The stochastic analysis was performed by making a series of 50 simulations using different transmissivity distributions based on the kriged data. The transmissivity value for each element was generated by random sampling from a log normal distribution using the $\log_{10}T$ and its variance determined from the kriging analysis.

5.3.2 Results of Flow Analysis

For each of the 50 simulations, the results of the flow analysis consisted of computed head values and estimates of discharge rates at boundaries. Plate 8 shows the predicted groundwater elevations averaged over the 50 simulations. Plate 9 shows the standard deviations in head values from the 50 simulations. The averaged conditions are comparable to observed data. In order to achieve a fair comparison, it was necessary to alter the basic statistical sampling procedure by setting a lower boundary for estimated transmissivity. A value of 2.4 ft/d was determined to provide the best comparison. If the transmissivity estimate based on sampling from the kriged data was less than 2.4 ft/d, the value for that element was set to 2.4 ft/d. That it was necessary to make this adjustment, indicates that slug test results showing very low transmissivities are not representative at the element scale of 10 feet by 10 feet. Figure 5.4 shows the distribution of transmissivities computed by the kriging program and one distribution based on the sampling procedure. The sampled

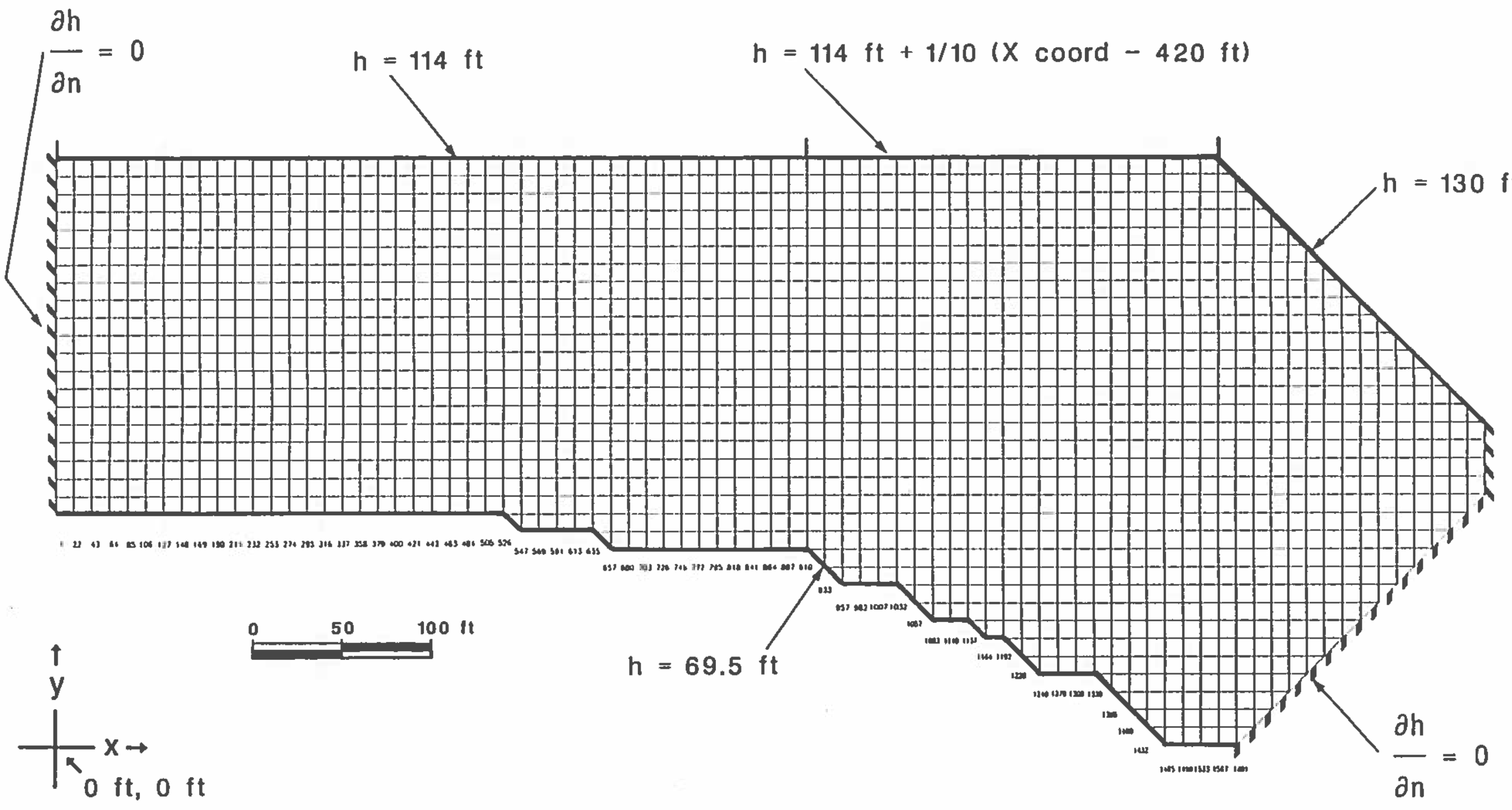

Figure 5.3. Finite-element grid showing boundary conditions used in flow simulations.

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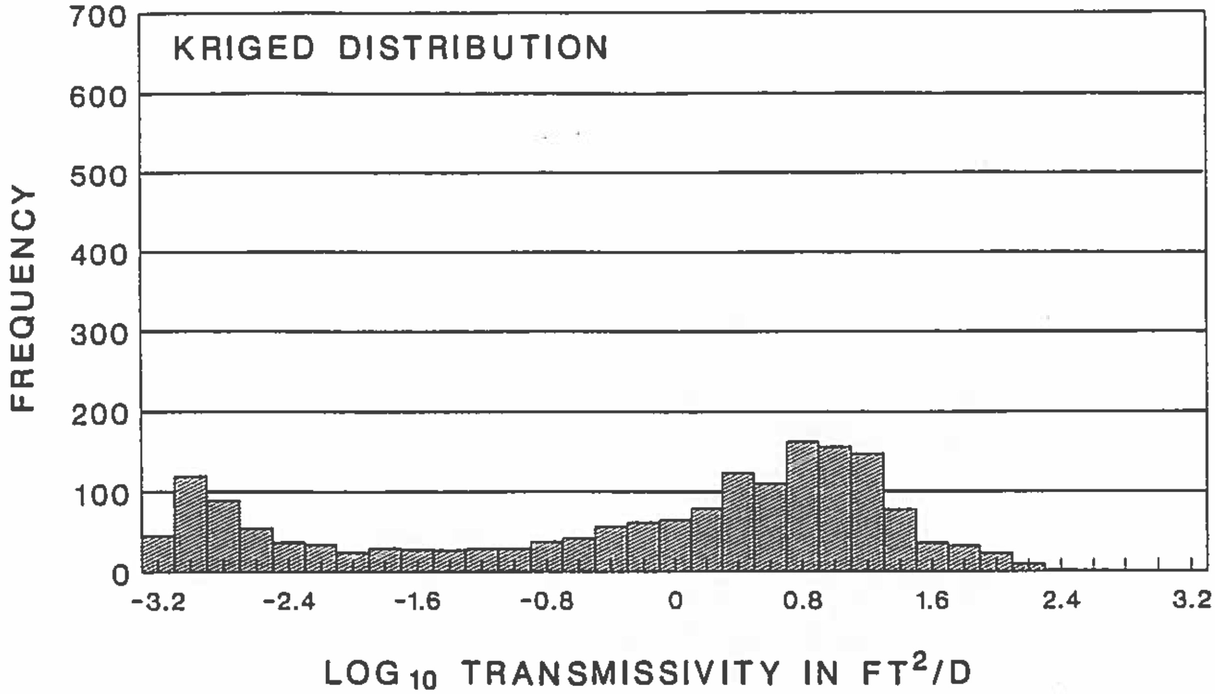

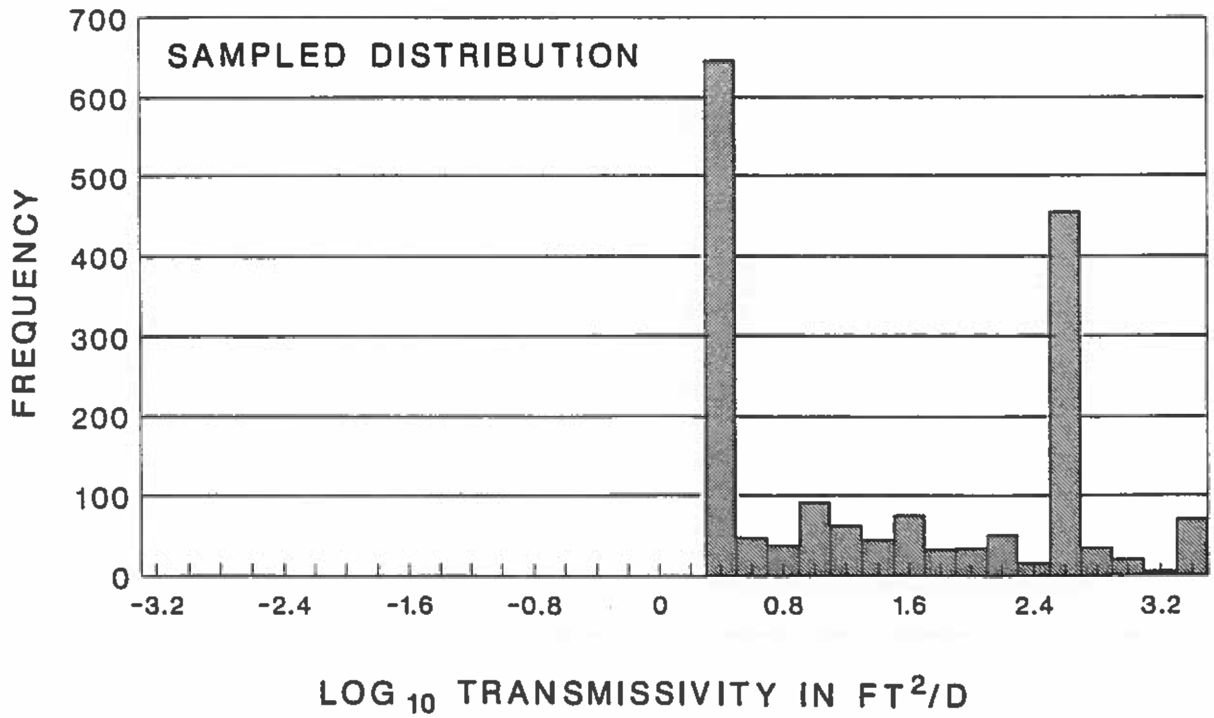

Figure 5.4. Distribution of transmissivity values for all elements in the numerical grid: above: mean values computed from kriging program; below: values based on statistical sampling procedure with lower bound of 2.4 ft^2/day for transmissivity.

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distribution has much higher transmissivities due to the lower bound of 2.4 ft^2/d.

The primary result of interest is discharge to Brandywine Creek. The results are tabulated in Table 5.3 for each node along the creek (see Plate 7 for reference). From the 50 simulations, the maximum discharge to the creek is 4345 ft^3/d (0.05 ft^3/s) and the minimum is 2022 ft^3/d (0.0234 ft^3/s). This discharge is small in comparison to the flow in the creek. As noted in Section 5.2, flow in the Brandywine Creek has averaged 477 ft^3/s over the 42 year period of record. Thus, the flow in the creek is about 10,000 times greater than groundwater discharge to the creek from the study area. The discharge estimates along the creek (from the series of simulations) together with measured groundwater concentrations of contaminant species can be used to compute mass loadings of contaminants to the creek.

Table 5.3. Discharge rates in ft^3/d calculated from SATURN.

Node #	Column	Row	Fluxes: Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8
1	1	14	-3.4	-3.27	-3.76	-2.84	-3.31	-1.64	-3.08	-2.67
22	2	14	-6.39	-6.55	-6.75	-5.69	-6.58	-9.52	-6.14	-5.34
43	3	14	-5.83	-6.59	-6.01	-5.68	-6.42	-9.56	-6.09	-6.16
64	4	14	-5.46	-5.85	-5.33	-5.68	-6.2	-4.16	-6.03	-6.97
85	5	14	-5.52	-5.14	-5.44	-5.67	-5.97	-4.87	-5.95	-6.98
106	6	14	-5.61	-5.53	-5.51	-5.66	-5.8	-4.85	-5.87	-6.18
127	7	14	-5.74	-5.89	-5.56	-5.64	-5.7	-5.59	-5.79	-5.38
148	8	14	-5.84	-5.91	-5.59	-5.62	-5.66	-6.36	-5.7	-5.39
169	9	14	-5.82	-5.59	-5.6	-5.59	-5.64	-6.39	-5.62	-5.41
190	10	14	-5.67	-5.27	-5.61	-5.55	-5.62	-5.67	-5.56	-5.42
211	11	14	-5.47	-5.25	-5.6	-5.49	-5.61	-4.97	-5.48	-5.41
232	12	14	-5.22	-5.2	-5.58	-5.37	-5.58	-5.01	-5.39	-5.38
253	13	14	-4.77	-5.12	-5.55	-5.06	-5.53	-5	-5.24	-5.33
274	14	14	-3.12	-5.02	-5.5	-5.35	-5.46	-4.91	-4.96	-5.25
295	15	14	-10.6	-4.88	-5.45	-6.85	-5.35	-4.67	-4.11	-5.14
316	16	14	-10.5	-4.7	-5.38	-5.67	-5.08	-3.87	-7.28	-4.98
337	17	14	-2.72	-4.47	-5.3	-5.65	-6.04	-6.75	-7.13	-4.73
358	18	14	-3.93	-4.17	-5.2	-5.8	-6.07	-6.48	-3.44	-4.3
379	19	14	-3.7	-3.78	-5.08	-3.97	-5.07	-2.33	-3.42	-3.2
400	20	14	-3.05	-3.21	-4.93	-3.44	-4.94	-6.54	-4.87	-8.95
421	21	14	-1.81	-2.9	-4.73	-5.33	-5.2	-6.39	-3.95	-7.92
442	22	14	-20.7	-4.48	-4.81	-5.72	-5.63	-2.62	-5.18	-3.34
463	23	14	-19	-5.7	-4.68	-2.48	-5.24	-3.21	-4.79	-3.34
484	24	14	-0.997	-7.65	-7.82	-8.82	-4.07	-2.71	-1.85	-4.95
505	25	14	-7.73	-7.01	-8.14	-12	-2.33	-3.6	-20.5	-6.82
526	26	14	-8.65	-18.8	-32.6	-14.2	-22.9	-14.2	-22.9	-5.5
547	27	13	-27.3	-26.6	-6.33	-2.6	-64.6	-6.67	-32.7	-1.03
569	28	13	-39	-16.3	-8.02	-16.3	-173	-11.4	-54.1	-83.3
591	29	13	-55.5	-14	-113	-30.7	-70.4	-312	-19.7	-93.5
613	30	13	-182	-224	-116	-278	-389	-228	-185	-175
635	31	13	-263	-261	-164	-270	-441	-11	-210	-233
657	32	12	-5.73	-15	-136	-222	-111	-9.23	-50.1	-33.1
680	33	12	-2.03	-136	-69.3	-213	-136	-72.2	-69.6	-24.4
703	34	12	-4.6	-239	-48.7	-6.55	-244	-97.7	-72.6	-19.1
726	35	12	-9.84	-109	-120	-6.05	-222	-97.4	-46.5	-47.1
749	36	12	-88.9	-39.8	-56	-215	-133	-117	-262	-33.9
772	37	12	-200	-80.4	-45.7	-286	-139	-58.6	-302	-129
795	38	12	-152	-49.7	-50.8	-56.5	-13	-12.2	-20.7	-117
818	39	12	-21.1	-11.6	-123	-8.34	-440	-41.4	-56.9	-0.752
841	40	12	-2.98	-62	-85.1	-8.96	-480	-130	-138	-37.1
864	41	12	-258	-70.8	-2.58	-5.46	-3.32	-168	-78.5	-41.7
887	42	12	-208	-46.9	-164	-129	-6.54	-92	-43.1	-150
910	43	12	-42.3	-60.3	-162	-154	-8.06	-55.5	-106	-134
933	44	11	-14.8	-8.02	-40.6	-15.2	-198	-19.2	-62.4	-15.9
957	45	10	-4.54	-1.6	-4.38	-15.1	-4.34	-6.68	-2.48	-1.78
982	46	10	-2.08	-7.95	-6.89	-36.5	-7.23	-8.87	-0.253	-16.3
1007	47	10	-8.49	-20.9	-19.4	-22.4	-8.97	-13.3	-8.35	-14.7
1032	48	10	-11.5	-20.9	-58.5	-4.84	-36.6	-6.48	-11.2	-24.7
1057	49	9	-13.6	-10.3	-11.9	-23.5	-41.1	-26.7	-22.6	-31.4
1083	50	8	-2.73	-3.39	-10.6	-11.3	-10.1	-26.2	-21.3	-14
1110	51	8	-3.13	-11	-10.9	-2.01	-7.36	-0.908	-6.24	-14.6
1137	52	8	-43.6	-13.1	-9.48	-26.7	-13.6	-10.2	-10.6	-41.5
1164	53	7	-11.1	-2.53	-2.01	-16.2	-15.5	-5.96	-1.95	-8.78
1192	54	7	-12.7	-31	-166	-8.02	-26.3	-6.17	-24.7	-12
1220	55	6	-15.5	-14.4	-7.82	-9.43	-9.52	-30.7	-17.7	-4.72
1249	56	5	-7.55	-8.76	-4	-24.5	-3.51	-1.43	-3.07	-41
1279	57	5	-9.23	-5.38	-48.2	-14.6	-55.9	-1.95	-18.1	-42.5
1309	58	5	-10.9	-9.27	-43.6	-21.9	-95.1	-29	-16.3	-3.88
1339	59	5	-24	-113	-23.8	-22	-47.4	-83.8	-43.5	-7.87
1369	60	4	-31.3	-72.5	-25.9	-132	-8.71	-4.54	-47.3	-65.1
1400	61	3	-8.44	-6.02	-29.3	-6.56	-17.7	-10.6	-6.57	-119
1432	62	2	-4.32	-33.1	-47.6	-66.9	-57.2	-51.7	-6.96	-2.89
1465	63	1	-0.328	-13.6	-11.5	-149	-15.3	-14.2	-78	-3.46
1499	64	1	-61.5	-15.5	-65.3	-75.5	-3.97	-14.4	-54.2	-1.83
1533	65	1	-165	-2.76	-62.3	-0.957	-3.1	-13	-0.537	-1.26
1567	66	1	-107	-115	-39.7	-77.9	-56.3	-280	-150	-53.3
1601	67	1	-142	-89.5	-25.6	-66.4	-371	-219	-109	-38.3
Sum of Fluxes (Run) :			-2444.865	-2239.81	-2417.32	-2912.69	-4344.73	-2547.15	-2637.13	-2074.19

Table 5.3. (Continued).

Node #	Column	Row	Fluxes: Run 9	Run 10	Run 11	Run 12	Run 13	Run 14	Run 15	Run 16
1	1	14	-2.81	-2.84	-3.02	-2.92	-2.92	-3.8	-2.98	-3.17
22	2	14	-5.61	-5.67	-6.02	-5.82	-5.84	-5.81	-5.94	-6.34
43	3	14	-5.6	-5.67	-6	-5.8	-5.82	-5.4	-5.9	-6.38
64	4	14	-5.59	-5.65	-5.95	-6.01	-5.79	-5.82	-5.85	-5.85
85	5	14	-5.56	-5.64	-5.9	-6.22	-5.76	-5.13	-5.8	-5.34
106	6	14	-5.54	-5.61	-5.85	-6.21	-5.71	-5.35	-5.78	-5.41
127	7	14	-5.5	-5.58	-5.8	-5.97	-5.67	-5.42	-5.76	-5.45
148	8	14	-5.46	-5.55	-5.75	-5.74	-5.62	-5.44	-5.75	-5.47
169	9	14	-5.42	-5.5	-5.7	-5.75	-5.57	-5.45	-5.74	-5.46
190	10	14	-5.37	-5.45	-5.64	-5.75	-5.5	-5.44	-5.73	-5.43
211	11	14	-5.3	-5.38	-5.58	-5.73	-5.38	-5.42	-5.71	-5.38
232	12	14	-5.23	-5.3	-5.51	-5.7	-4.98	-5.39	-5.68	-5.31
253	13	14	-5.14	-5.19	-5.43	-5.64	-6.75	-5.34	-5.62	-5.22
274	14	14	-5.02	-5.05	-5.3	-5.57	-6.72	-5.29	-5.54	-5.12
295	15	14	-4.88	-4.87	-5.11	-5.47	-4.87	-5.21	-5.43	-5.07
316	16	14	-4.69	-4.61	-4.74	-5.34	-5.16	-5.12	-5.26	-5.08
337	17	14	-4.41	-4.23	-3.45	-5.18	-5.14	-5.01	-5.85	-5.03
358	18	14	-3.93	-4.17	-8.86	-4.96	-5.01	-4.86	-6.5	-4.73
379	19	14	-2.55	-4.21	-8.75	-4.65	-4.74	-4.69	-6.34	-3.74
400	20	14	-8.67	-4.88	-2.86	-4.14	-4.08	-4.58	-5.39	-5.42
421	21	14	-8.13	-8.54	-3.26	-2.77	-3.77	-5.1	-4.32	-6.66
442	22	14	-1.62	-6.04	-5.28	-8.17	-4.57	-11.4	-3.9	-3.19
463	23	14	-1.98	-1.52	-4.48	-7.69	-9.31	-12.3	-3.52	-4.96
484	24	14	-5.03	-2.15	-5.64	-1.73	-11.1	-6.9	-2.84	-4.53
505	25	14	-5.53	-7.87	-15.1	-1.71	-28	-8.08	-8.01	-5.87
526	26	14	-2.62	-9.46	-80.5	-34.7	-112	-11.2	-8.93	-47.5
547	27	13	-9.73	-6.65	-22.3	-4.69	-97.1	-5.75	-24.9	-25.2
569	28	13	-9.24	-5.6	-172	-1.37	-12.4	-99.2	-31.9	-6.73
591	29	13	-130	-65.1	-158	-14.9	-12.7	-78.3	-23	-1.47
613	30	13	-128	-74	-66.6	-387	-10.5	-14.6	-18.9	-183
635	31	13	-40.7	-71.1	-221	-320	-44.5	-137	-145	-439
657	32	12	-23.4	-75.3	-240	-15.1	-200	-181	-301	-98.5
680	33	12	-10.3	-276	-279	-45.7	-179	-205	-202	-31.9
703	34	12	-158	-292	-267	-96.2	-98.9	-20.3	-35.8	-25.9
726	35	12	-359	-20	-114	-47.5	-178	-12.2	-24.3	-29.3
749	36	12	-164	-74.4	-56.1	-38.4	-148	-408	-63.4	-289
772	37	12	-9.89	-93.7	-23.7	-41.3	-153	-386	-67.6	-259
795	38	12	-2.52	-76.3	-233	-290	-85.8	-23.6	-51	-1.74
818	39	12	-16.7	-110	-301	-200	-107	-71.9	-18.5	-72.4
841	40	12	-19.3	-47.2	-93.7	-11.7	-317	-101	-102	-72.9
864	41	12	-41	-9.94	-27.6	-12	-128	-53.3	-184	-6.34
887	42	12	-42.4	-14.2	-49.6	-34	-5	-2.92	-54.6	-32.4
910	43	12	-5.57	-23.7	-55.4	-50.7	-3.78	-37.5	-37	-222
933	44	11	-14.5	-357	-104	-16.2	-11.7	-48.7	-37.3	-44.4
957	45	10	-66.1	-28.8	-29.3	-7.2	-8.91	-6.47	-8.16	-10.3
982	46	10	-66.1	-37.8	-26.3	-2.64	-14.7	-2.03	-6.59	-15.3
1007	47	10	-3.42	-2.71	-2.69	-54.8	-33.7	-3.22	-13.8	-23.3
1032	48	10	-5.79	-6.06	-11.1	-74.3	-32.8	-46.4	-53.5	-10.6
1057	49	9	-5.67	-3.97	-8.04	-13.1	-5.79	-35.7	-39.9	-8.4
1083	50	8	-14.4	-4.58	-0.528	-8.86	-7.78	-13.7	-2.78	-14.6
1110	51	8	-13.5	-5.12	-8.64	-3.81	-23.2	-2.47	-5.37	-15.2
1137	52	8	-2.66	-4.67	-41.1	-184	-14.7	-3.71	-10.2	-15.9
1164	53	7	-10.7	-2.38	-1.72	-9.44	-5.69	-23.9	-5.42	-3.32
1192	54	7	-9.65	-15.4	-2.13	-6.48	-10.4	-21	-16.9	-31.8
1220	55	6	-7.88	-14.7	-2.04	-7.58	-25.8	-24.4	-16.7	-26.5
1249	56	5	-3.23	-17.8	-9.78	-11.4	-0.352	-1.09	-2.15	-9.71
1279	57	5	-3.75	-17.9	-60.8	-7.99	-25	-0.866	-0.935	-5.24
1309	58	5	-12.2	-17.8	-64.1	-5.45	-32.2	-9.03	-35.7	-32.4
1339	59	5	-139	-30	-15.3	-136	-19.9	-11.5	-34.6	-102
1369	60	4	-21.7	-6.87	-5.9	-89.9	-45.5	-19.6	-168	-83.2
1400	61	3	-43.6	-3.75	-40.4	-22	-2.28	-299	-126	-9.17
1432	62	2	-113	-454	-42.9	-35.8	-189	-4.69	-4.46	-17.6
1465	63	1	-7.59	-0.768	-113	-11.5	-77.2	-0.594	-2.2	-3.85
1499	64	1	-96.7	-0.554	-68.2	-11.6	-115	-8.56	-2.39	-1.82
1533	65	1	-102	-39.3	-1.78	-9.92	-55.6	-11.5	-0.714	-81
1567	66	1	-23.4	-37.4	-1.71	-6.1	-10.6	-36.2	-17.6	-81
1601	67	1	-17.2	-0.448	-244	-64.7	-10.8	-39.1	-129	-3.66
Sum of Fluxes (Run) :			-2100.68	-2581.6	-3510.93	-2576.67	-2835.06	-2669.95	-2269.33	-2624.16

Table 5.3. (Continued).

Node #	Column	Row	Fluxes: Run 17	Run 18	Run 19	Run 20	Run 21	Run 22	Run 23	Run 24
1	1	14	-2.63	-2.91	-2.75	-2.98	-2.77	-3.04	-2.97	-2.84
22	2	14	-7.29	-5.83	-5.5	-5.97	-5.52	-6.08	-5.94	-5.67
43	3	14	-7.8	-5.87	-5.5	-5.96	-5.84	-6.07	-5.93	-5.67
64	4	14	-6.68	-5.89	-5.5	-5.95	-6.17	-6.05	-5.91	-5.66
85	5	14	-6.09	-5.86	-5.5	-5.93	-6.16	-6.03	-5.89	-5.65
106	6	14	-5.43	-5.79	-5.5	-5.91	-5.83	-6	-5.87	-5.63
127	7	14	-5.44	-5.69	-5.49	-5.88	-5.5	-5.97	-5.84	-5.61
148	8	14	-5.47	-5.59	-5.48	-5.84	-5.51	-5.92	-5.81	-5.59
169	9	14	-5.51	-5.5	-5.47	-5.8	-5.51	-5.87	-5.78	-5.56
190	10	14	-5.54	-5.4	-5.45	-5.73	-5.5	-5.8	-5.75	-5.51
211	11	14	-5.55	-5.27	-5.43	-5.62	-5.47	-5.7	-5.73	-5.35
232	12	14	-5.54	-5.07	-5.39	-5.46	-5.44	-5.55	-5.7	-6.26
253	13	14	-5.48	-4.72	-5.34	-5.13	-5.39	-5.3	-5.67	-6.27
274	14	14	-5.33	-3.72	-5.28	-4.08	-5.32	-4.81	-5.62	-5.33
295	15	14	-4.73	-3.63	-5.2	-8.4	-5.23	-3.06	-5.55	-5.4
316	16	14	-7.5	-10.9	-5.11	-8.24	-5.1	-10.8	-5.4	-5.29
337	17	14	-7.46	-9.04	-5.03	-3.22	-4.95	-10.8	-4.96	-5.16
358	18	14	-4.57	-2.51	-4.96	-5.11	-4.78	-2.75	-6.67	-5.01
379	19	14	-5.04	-3.67	-4.85	-4.86	-4.61	-4.22	-6.6	-4.85
400	20	14	-5.03	-3.78	-4.61	-3.26	-4.41	-4.46	-4.65	-4.66
421	21	14	-4.85	-3.74	-4.33	-3.33	-4.14	-4.54	-4.37	-4.39
442	22	14	-5.02	-3.57	-4.06	-11.1	-3.75	-4.62	-7.95	-3.98
463	23	14	-5.27	-2.85	-3.71	-11.4	-3.08	-4.73	-8.05	-2.97
484	24	14	-5.43	-5.59	-2.62	-3.35	-2.01	-4.72	-5.43	-3
505	25	14	-4.33	-5.44	-4.31	-2.65	-7.43	-4.57	-10.9	-10.7
526	26	14	-11.3	-40.7	-14.7	-163	-8.35	-6.52	-13.2	-11.9
547	27	13	-5.72	-70.8	-71.8	-18.7	-1.72	-8.48	-23.6	-0.754
569	28	13	-3.58	-149	-45.6	-15.3	-53.8	-10.4	-156	-0.767
591	29	13	-29.8	-320	-80.8	-7.64	-282	-28.2	-283	-65.2
613	30	13	-32.6	-129	-204	-15	-177	-106	-209	-71.8
635	31	13	-535	-362	-119	-105	-343	-177	-111	-639
657	32	12	-3.3	-84.5	-15.8	-9.26	-219	-94.2	-53.8	-36.5
680	33	12	-216	-45.3	-7.72	-171	-195	-47.5	-42.2	-44.8
703	34	12	-414	-31.7	-21.9	-211	-10.1	-29.8	-9.54	-43.1
726	35	12	-191	-92.2	-112	-74.6	-6.97	-60	-95.4	-57.2
749	36	12	-3.76	-55.1	-99.9	-65	-48	-183	-92.9	-251
772	37	12	-2.73	-31.7	-49.1	-65.9	-212	-147	-103	-181
795	38	12	-165	-46.5	-52.3	-80.9	-142	-67.8	-216	-9.87
818	39	12	-150	-40.9	-7.58	-4.06	-53.8	-20.4	-73.1	-1.59
841	40	12	-15.9	-24.3	-79.5	-7.06	-108	-15.9	-6.05	-159
864	41	12	-222	-39.3	-85.3	-243	-77.2	-168	-16.9	-240
887	42	12	-216	-42.5	-10.2	-166	-16.8	-171	-351	-156
910	43	12	-98	-153	-78.6	-293	-9.88	-2.59	-344	-150
933	44	11	-3.88	-80	-111	-79.6	-106	-13.3	-17.4	-26.7
957	45	10	-2.75	-7.89	-14.7	-22.4	-61.7	-6.13	-7.1	-13.4
982	46	10	-2.67	-1.47	-5.56	-2.31	-35.6	-9.6	-12.7	-14.4
1007	47	10	-5.02	-19.2	-26.7	-2.22	-39.3	-9.25	-9.32	-4.53
1032	48	10	-12.4	-41.6	-26.6	-15.4	-33.5	-96.2	-10.7	-31.3
1057	49	9	-6.79	-1.98	-12.5	-39.1	-35.3	-5.53	-5.44	-8.94
1083	50	8	-19.3	-1.54	-5.75	-1.22	-6.83	-11.8	-1.7	-3.59
1110	51	8	-14.9	-3.85	-4.65	-5.59	-6.92	-10.6	-4.69	-37.4
1137	52	8	-6.5	-9.27	-14.1	-6.76	-45.5	-9.56	-42.5	-53.3
1164	53	7	-3.76	-8.3	-3.94	-11.8	-4.98	-3.2	-6.07	-3.27
1192	54	7	-4.19	-10.7	-129	-26	-8.22	-8.23	-32.5	-17.9
1220	55	6	-11	-2.17	-9	-16.8	-8.11	-6.52	-30.9	-15.6
1249	56	5	-11.1	-30.6	-3.76	-10.7	-6.55	-6.22	-1.52	-9.97
1279	57	5	-44.2	-28.4	-30.2	-7.18	-7.66	-27.5	-5.11	-5.99
1309	58	5	-38.1	-3.44	-47.7	-63.8	-15.4	-25.4	-31.3	-48.7
1339	59	5	-8.33	-3.37	-22.2	-66.6	-20.4	-12.2	-76.3	-89.2
1369	60	4	-32	-77.1	-18.5	-57.5	-20.5	-38	-140	-22.9
1400	61	3	-84	-31.2	-111	-58.4	-128	-152	-7.52	-17.7
1432	62	2	-14.9	-1.59	-13.2	-7.17	-161	-7.53	-10.2	-3.56
1465	63	1	-10.7	-2.48	-0.501	-4.54	-4.66	-8	-12	-33.1
1499	64	1	-11.9	-2.8	-7.55	-1.25	-15.7	-4.23	-95.8	-24.1
1533	65	1	-78.9	-2.2	-32.9	-57.4	-17.3	-94.1	-63.9	-103
1567	66	1	-144	-0.601	-27	-43.6	-69	-127	-6.72	-119
1601	67	1	-86.2	-458	-65.6	-5.7	-69	-5.35	-8.42	-2.49
Sum of Fluxes (Run) :			-3112.19	-2716.08	-2021.78	-2469.62	-3017.17	-2178.7	-2988.44	-2961.53

Table 5.3. (Continued).

Node #	Column	Row	Fluxes: Run 25	Run 26	Run 27	Run 28	Run 29	Run 30	Run 31	Run 32
1	1	14	-2.87	-2.87	-2.93	-3.11	-2.93	-2.74	-2.85	-2.82
22	2	14	-5.74	-5.73	-5.87	-6.22	-5.87	-5.48	-5.69	-5.64
43	3	14	-5.74	-5.73	-5.88	-6.25	-5.87	-6.4	-5.68	-5.63
64	4	14	-5.73	-5.72	-5.86	-5.86	-5.9	-7.33	-5.68	-5.63
85	5	14	-5.72	-5.69	-5.82	-5.48	-5.97	-7.27	-5.66	-5.62
106	6	14	-5.71	-5.65	-5.74	-5.52	-6.02	-6.24	-5.65	-5.6
127	7	14	-5.7	-5.62	-5.65	-5.55	-6	-5.21	-5.63	-5.59
148	8	14	-5.68	-5.58	-5.55	-5.55	-5.89	-5.16	-5.6	-5.58
169	9	14	-5.65	-5.55	-5.46	-5.53	-5.77	-5.15	-5.57	-5.65
190	10	14	-5.61	-5.51	-5.41	-5.5	-5.68	-5.12	-5.53	-5.8
211	11	14	-5.56	-5.46	-5.38	-5.45	-5.59	-5.06	-5.49	-5.93
232	12	14	-5.47	-5.4	-5.14	-5.38	-5.44	-4.97	-5.43	-5.9
253	13	14	-5.32	-5.33	-3.69	-5.29	-5.01	-4.83	-5.36	-5.7
274	14	14	-5.02	-5.23	-9.93	-5.17	-6.72	-5.28	-5.28	-5.47
295	15	14	-3.99	-5.1	-9.85	-4.99	-6.65	-5.77	-5.17	-5.29
316	16	14	-8.11	-4.92	-3.09	-4.72	-4.77	-5.66	-5.04	-5.19
337	17	14	-7.9	-4.63	-4.25	-4.22	-5.02	-4.93	-4.88	-5.06
358	18	14	-2.76	-4.12	-4.42	-2.65	-4.97	-4.13	-4.88	-4.9
379	19	14	-6.33	-2.58	-4.36	-8.68	-4.84	-3.87	-4.89	-4.68
400	20	14	-6.71	-8.52	-4.17	-8.53	-4.63	-3.46	-4.67	-4.37
421	21	14	-3.9	-10	-3.86	-1.64	-4.44	-3.01	-4.2	-4.09
442	22	14	-4.26	-3.45	-3.25	-1.62	-3.41	-2.1	-3.57	-4.52
463	23	14	-3.63	-4.17	-3.53	-5.85	-8.96	-10.9	-3.2	-4.01
484	24	14	-6.68	-5.15	-2.58	-9.83	-9.67	-12.9	-2.82	-2.47
505	25	14	-7	-11	-11	-5.49	-31.4	-3.81	-3.16	-8.48
526	26	14	-10.8	-11.7	-31.7	-9.28	-27.6	-7.5	-11.1	-10.2
547	27	13	-12	-1.62	-5.99	-9.31	-3.07	-1.63	-0.351	-11.2
569	28	13	-11.5	-3.12	-3	-37.1	-21.9	-170	-37.1	-10.6
591	29	13	-345	-109	-1.76	-117	-115	-190	-44.4	-185
613	30	13	-312	-83.7	-141	-212	-84.2	-15.1	-3.15	-190
635	31	13	-35	-109	-472	-217	-177	-191	-678	-109
657	32	12	-5.3	-91.6	-181	-19	-8.43	-51.7	-149	-44.7
680	33	12	-75.3	-79.6	-54.2	-288	-405	-37.1	-125	-6.91
703	34	12	-72	-49.9	-126	-297	-333	-18.4	-48.6	-46.6
726	35	12	-75.3	-69.3	-125	-9.85	-46.1	-500	-51	-66
749	36	12	-218	-5.83	-95.8	-20.2	-9.51	-483	-65.7	-47.3
772	37	12	-97.8	-5.56	-57.1	-32.8	-11	-27.4	-72.2	-65.6
795	38	12	-89.9	-121	-39.2	-38.8	-36.2	-32.5	-70.4	-66.9
818	39	12	-69.8	-173	-28.7	-26.6	-327	-17	-70.2	-44.2
841	40	12	-53.7	-127	-10.4	-16.9	-278	-9.46	-94.9	-47.7
864	41	12	-43.7	-74.2	-8.42	-23.8	-2.17	-75.6	-107	-57.1
887	42	12	-7.51	-127	-4.49	-33.7	-58.2	-143	-142	-8.9
910	43	12	-300	-122	-84.3	-101	-51.6	-88.3	-131	-292
933	44	11	-10.5	-2.28	-13.1	-70.8	-51.8	-17.5	-23.2	-18.2
957	45	10	-6.06	-29.7	-40.1	-0.537	-35.7	-16.4	-17	-12.9
982	46	10	-6.28	-29.1	-39.5	-29.1	-41.7	-12	-12	-13.3
1007	47	10	-21.5	-28.5	-8.78	-24.2	-45.2	-4.06	-6.29	-5.09
1032	48	10	-29.3	-28.7	-9.72	-12.4	-20	-10	-8.82	-14.6
1057	49	9	-19.8	-11.8	-1.26	-8.68	-25.8	-8.64	-7.07	-21.1
1083	50	8	-15.7	-3.86	-1.48	-5.82	-0.77	-0.392	-2.2	-18.5
1110	51	8	-12.8	-15.7	-27.5	-3.68	-38.1	-3.07	-8.32	-7.24
1137	52	8	-17.1	-18	-36.3	-4.9	-67.2	-76.1	-9.48	-9.08
1164	53	7	-7.64	-4.2	-8.06	-9.43	-40.8	-20.2	-2.36	-18.5
1192	54	7	-49.8	-50.2	-12.8	-25	-5.77	-15.5	-16.8	-30.7
1220	55	6	-23.9	-76.9	-5.49	-26	-39.2	-14.6	-31.3	-72
1249	56	5	-1.58	-36.3	-2.25	-8.65	-2.65	-17.9	-0.46	-0.187
1279	57	5	-25.4	-38.1	-1.17	-6.56	-7.05	-40.3	-14.5	-2.93
1309	58	5	-29.3	-10.3	-26.7	-15.1	-7.84	-36.6	-28.3	-26.5
1339	59	5	-69.6	-37.8	-29	-12.8	-24.4	-28.6	-116	-26.7
1369	60	4	-294	-22.9	-251	-3.71	-154	-26.6	-3.41	-12
1400	61	3	-1.19	-41.6	-8.91	-98.3	-67.8	-17.9	-104	-146
1432	62	2	-120	-5.5	-3.31	-91.1	-104	-24.8	-13.1	-61.6
1465	63	1	-0.287	-2.51	-12.3	-16.8	-20.2	-63.7	-18.3	-15.9
1499	64	1	-0.323	-23	-12.2	-51.2	-47.3	-50.3	-18.5	-16.3
1533	65	1	-69.3	-51.6	-5.6	-22.6	-21.6	-9.34	-2.68	-26.2
1567	66	1	-84.1	-71.1	-23	-4.29	-44.8	-24.2	-31.5	-30.9
1601	67	1	-29.1	-38.5	-21.5	-176	-41.5	-24.2	-25	-16.4
Sum of Fluxes (Run) :			-2915.96	-2180.99	-2203.76	-2371.07	-3117.58	-2758.37	-2543.27	-2062.35

Table 5.3. (Continued).

Node #	Column	Row	Fluxes: Run 33	Run 34	Run 35	Run 36	Run 37	Run 38	Run 39	Run 40
1	1	14	-2.91	-2.88	-3.05	-2.84	-2.91	-3.43	-2.8	-2.8
22	2	14	-5.82	-5.75	-6.17	-5.68	-5.82	-6.85	-5.58	-5.58
43	3	14	-5.81	-5.73	-6.3	-5.66	-5.82	-6.62	-5.5	-5.56
64	4	14	-5.8	-5.69	-6.25	-5.64	-5.81	-6.07	-5.32	-6.03
85	5	14	-5.79	-5.64	-6.03	-5.6	-5.81	-5.55	-4.69	-6.52
106	6	14	-5.78	-5.68	-5.78	-5.53	-5.8	-5.54	-7.42	-6.48
127	7	14	-5.77	-6	-5.6	-5.4	-5.81	-5.57	-7.39	-5.84
148	8	14	-5.77	-6.29	-5.48	-5.13	-5.84	-5.59	-4.56	-5.19
169	9	14	-5.76	-6.14	-5.31	-4.12	-5.91	-5.59	-5.1	-5.19
190	10	14	-5.75	-5.72	-4.99	-8.75	-6.02	-5.59	-5.19	-5.17
211	11	14	-5.73	-5.34	-3.83	-8.71	-6.08	-5.57	-5.2	-5.14
232	12	14	-5.71	-5.26	-9.28	-3.97	-6.04	-5.54	-5.16	-5.08
253	13	14	-5.68	-5.14	-9.28	-4.85	-5.89	-5.49	-5.09	-4.99
274	14	14	-5.64	-4.91	-3.83	-4.97	-5.67	-5.44	-4.99	-4.86
295	15	14	-5.58	-4.46	-4.9	-4.91	-5.44	-5.37	-4.86	-4.68
316	16	14	-5.5	-2.89	-5.02	-5.14	-5.2	-5.28	-4.66	-5.08
337	17	14	-5.4	-9.52	-4.96	-5.36	-4.89	-5.17	-4.33	-5.54
358	18	14	-5.27	-9.44	-4.85	-5.17	-4.45	-5.04	-3.51	-5.24
379	19	14	-5.11	-2.39	-4.74	-4.54	-3.69	-4.86	-5.69	-4.92
400	20	14	-4.91	-3.5	-4.61	-3.74	-2.67	-4.82	-5.03	-4.57
421	21	14	-4.67	-3.49	-4.29	-2.76	-1.83	-4.79	-2.82	-3.63
442	22	14	-4.44	-3.2	-3	-6.07	-9.84	-4.24	-11.5	-2.38
463	23	14	-4.14	-2.72	-5.58	-6.23	-13.2	-8.22	-8.59	-4.61
484	24	14	-2.7	-1.66	-8.6	-2.44	-2.49	-12.3	-2.19	-4.47
505	25	14	-14.9	-5.9	-3.88	-8.31	-2.69	-8.42	-4.77	-5.45
526	26	14	-24.9	-23	-36.1	-39.1	-9.31	-42.2	-7.11	-62.1
547	27	13	-14.1	-13.7	-3.85	-12.9	-42.2	-14.5	-23.3	-18.1
569	28	13	-16.5	-100	-73.4	-3.47	-36.2	-9.84	-21.2	-111
591	29	13	-3.09	-120	-65.4	-68.9	-97.1	-11.3	-174	-134
613	30	13	-11.5	-213	-6.98	-103	-98.7	-58.4	-193	-78.5
635	31	13	-453	-499	-160	-448	-8.6	-134	-36.9	-199
657	32	12	-4.09	-176	-6.08	-138	-129	-31.7	-11	-79.4
680	33	12	-56.6	-123	-116	-166	-188	-6.5	-58.9	-56.3
703	34	12	-92.1	-68.1	-140	-22.8	-72.4	-329	-74.3	-256
726	35	12	-40.4	-27.6	-30	-50.1	-59.7	-566	-14.3	-247
749	36	12	-40.7	-66.6	-43.2	-49.3	-58.5	-211	-241	-24.3
772	37	12	-66	-48.9	-155	-5.33	-17.5	-67.1	-215	-55.3
795	38	12	-34.9	-12.8	-135	-20.3	-134	-156	-27.7	-142
818	39	12	-13.3	-105	-29.2	-39.7	-155	-74.4	-144	-91.6
841	40	12	-32.8	-153	-28.8	-147	-16.3	-91.7	-111	-63
864	41	12	-46.4	-59.3	-7.48	-357	-204	-84.5	-12.9	-50.1
887	42	12	-99.1	-8.14	-143	-244	-206	-108	-37.7	-26.1
910	43	12	-65.4	-129	-201	-48.6	-22.9	-161	-152	-45.1
933	44	11	-24.7	-40.8	-38.3	-16	-24.7	-82.3	-26.5	-20.6
957	45	10	-11	-0.285	-8.41	-9.99	-4.13	-5.84	-22.6	-13.2
982	46	10	-24.3	-5.06	-7.62	-3.37	-2.62	-26.1	-0.528	-4.81
1007	47	10	-17.9	-4.89	-12.1	-2.73	-14	-20.6	-3.25	-2.32
1032	48	10	-81.9	-8.23	-21	-73.1	-14.8	-68.9	-5.72	-20.6
1057	49	9	-38.4	-18	-15.2	-13	-5.86	-36.7	-7.73	-5.76
1083	50	8	-25.2	-1.89	-3.13	-1.7	-34.1	-1.12	-7.51	-12
1110	51	8	-8.67	-11	-4.03	-39.5	-34.6	-13	-8.06	-11.4
1137	52	8	-38.6	-22.9	-21.7	-30.5	-6.7	-20.7	-6.32	-15.4
1164	53	7	-15.7	-1.27	-16.8	-2.79	-24.6	-9.58	-18.1	-3.35
1192	54	7	-24.4	-14.5	-11.8	-5.49	-23.3	-20.1	-59.5	-14.5
1220	55	6	-19.1	-10.7	-15.8	-14.1	-12.2	-11.7	-18.2	-4.61
1249	56	5	-6.44	-4.84	-13	-1.22	-3.29	-78.4	-1.41	-7.48
1279	57	5	-8.44	-3.35	-27.7	-13.5	-10.4	-60.7	-13.8	-13.9
1309	58	5	-16	-4.77	-28.6	-33.5	-10.9	-7.1	-31.4	-20.4
1339	59	5	-65	-42.2	-3.18	-48.4	-13	-11.3	-50.5	-125
1369	60	4	-32.8	-26.4	-11.1	-23.9	-9.76	-124	-34.1	-122
1400	61	3	-22.4	-200	-7.61	-13.1	-79.6	-10.1	-46.5	-18.2
1432	62	2	-6.55	-16.3	-256	-29.9	-357	-19.8	-37.3	-5.66
1465	63	1	-25.7	-4.2	-93.2	-197	-54	-39.2	-5.2	-34
1499	64	1	-113	-4.33	-105	-144	-7.93	-31.2	-111	-36.5
1533	65	1	-105	-1.29	-6.27	-6.76	-6.51	-16	-238	-20
1567	66	1	-189	-174	-17.8	-9.29	-1.69	-20.9	-96.3	-58.8
1601	67	1	-162	-166	-8.54	-81.1	-10.4	-40.7	-13.1	-43.7
Sum of Fluxes (Run) :			-2337.42	-2858.68	-2269.99	-2908.96	-2457.12	-3080.13	-2549.87	-2498.09

Table 5.3. (Continued).

Node #	Column	Row	Fluxes: Run 41	Run 42	Run 43	Run 44	Run 45	Run 46	Run 47	Run 48
1	1	14	-2.97	-2.74	-3.22	-2.96	-2.8	-2.93	-3.18	-3.04
22	2	14	-5.9	-5.47	-6.43	-5.92	-5.6	-5.86	-6.34	-6.03
43	3	14	-5.82	-5.47	-6.29	-5.91	-5.59	-5.85	-6.21	-5.91
64	4	14	-5.76	-5.45	-5.9	-5.9	-5.57	-5.84	-5.96	-5.69
85	5	14	-5.72	-5.44	-5.52	-5.88	-5.53	-5.82	-5.71	-5.35
106	6	14	-5.71	-5.41	-5.4	-5.86	-5.49	-5.8	-5.58	-4.46
127	7	14	-5.71	-5.38	-5.4	-5.83	-5.44	-5.76	-5.56	-8.2
148	8	14	-5.73	-5.34	-5.41	-5.8	-5.38	-5.71	-5.55	-8.18
169	9	14	-5.77	-5.3	-5.4	-5.77	-5.31	-5.65	-5.53	-4.36
190	10	14	-5.79	-5.23	-5.38	-5.73	-5.2	-5.55	-5.51	-5.13
211	11	14	-5.76	-5.15	-5.33	-5.68	-5.06	-5.42	-5.47	-5.3
232	12	14	-5.7	-5.02	-5.25	-5.62	-4.78	-5.17	-5.42	-5.35
253	13	14	-5.61	-4.81	-5.12	-5.54	-5.9	-4.44	-5.35	-5.35
274	14	14	-5.53	-4.2	-4.9	-5.44	-6.04	-6.36	-5.26	-5.31
295	15	14	-5.46	-6.47	-4.48	-5.3	-5.04	-5.2	-5.16	-5.25
316	16	14	-5.38	-6.34	-3.2	-5.1	-4.63	-8.44	-5.02	-5.16
337	17	14	-5.28	-3.72	-7.03	-4.74	-4.68	-8.65	-4.86	-5.04
358	18	14	-5.14	-3.95	-6.11	-3.72	-5.15	-2.59	-4.67	-4.89
379	19	14	-5.03	-3.74	-6.69	-7.37	-4.96	-2.56	-4.43	-4.69
400	20	14	-4.86	-3.35	-10.8	-7.18	-4.14	-7.79	-4.19	-4.44
421	21	14	-4.41	-2.73	-4.02	-2.86	-3.67	-7.6	-3.93	-4.12
442	22	14	-3.2	-1.85	-3.16	-3.09	-3.89	-3.32	-3.47	-3.71
463	23	14	-12.9	-1.02	-3.53	-2	-3.67	-4.39	-4.41	-3.17
484	24	14	-11.5	-25.2	-1.48	-9.31	-7.09	-3.72	-4.78	-2.97
505	25	14	-3.62	-25.6	-1.16	-13.5	-9.7	-4.31	-4.02	-5.63
526	26	14	-11.5	-2.89	-39.8	-19.2	-7.54	-5.69	-5.54	-8.74
547	27	13	-8.19	-4.98	-12.1	-90.1	-3.89	-1.61	-2.78	-3.66
569	28	13	-62.9	-50.6	-77.1	-64.1	-70.6	-23	-17.2	-18.4
591	29	13	-64.4	-81.4	-179	-83.3	-81.9	-21.3	-17.3	-23.5
613	30	13	-418	-310	-177	-83.4	-88.8	-436	-1.7	-8.53
635	31	13	-310	-359	-151	-407	-190	-786	-408	-237
657	32	12	-122	-94.7	-29.9	-116	-237	-15.7	-24.3	-32.1
680	33	12	-192	-28.2	-38.1	-47.2	-194	-60.6	-47.6	-180
703	34	12	-170	-74	-107	-43.2	-92.3	-57.5	-52.4	-180
726	35	12	-102	-111	-103	-101	-216	-10.3	-7.8	-53.5
749	36	12	-5.44	-79.5	-13.4	-100	-164	-12.2	-18.9	-16.2
772	37	12	-88.6	-50.6	-387	-71.8	-36.3	-93.4	-110	-7.12
795	38	12	-96.6	-103	-328	-91.4	-10.3	-253	-91.6	-92.4
818	39	12	-17.7	-224	-89.6	-75.6	-98.2	-142	-83.3	-159
841	40	12	-101	-146	-91.7	-57.9	-79.6	-111	-348	-56
864	41	12	-113	-6.5	-17.3	-91	-202	-96.1	-243	-74.3
887	42	12	-69.3	-6.36	-27.2	-105	-163	-14.8	-43.2	-77.2
910	43	12	-136	-47.2	-49.2	-79.2	-39.4	-9.9	-13.3	-206
933	44	11	-40.3	-50.3	-33.7	-21.2	-7.73	-10.9	-21.4	-5.03
957	45	10	-7.49	-43.5	-3.59	-2.24	-3.54	-33.1	-18.5	-4.81
982	46	10	-8.96	-52.1	-5.11	-15.7	-4.21	-23.9	-1.34	-5.28
1007	47	10	-4.69	-29	-15.9	-18.2	-4.42	-4.56	-31.9	-6.2
1032	48	10	-15.7	-30	-25	-20.4	-23.3	-16.3	-34.8	-15.5
1057	49	9	-16.2	-39.9	-12.1	-29.1	-7.42	-9.02	-6.74	-24.8
1083	50	8	-9.97	-4.85	-4.7	-5.1	-4.37	-1.44	-2.35	-17.6
1110	51	8	-7.41	-10.8	-6.43	-7.04	-3.11	-51.3	-1.88	-7.51
1137	52	8	-17.4	-19.4	-15.9	-9.19	-5.3	-57	-15.5	-9.82
1164	53	7	-7.67	-24.1	-17.2	-10.5	-11.7	-7.32	-3.21	-4.72
1192	54	7	-15	-12.8	-14.4	-20.2	-16.2	-16.9	-57.9	-10.9
1220	55	6	-37.4	-8.39	-17.2	-10.7	-50	-26.3	-23.8	-8.49
1249	56	5	-32.3	-9.22	-29.6	-18.1	-11.3	-17.9	-10.6	-3.72
1279	57	5	-14.2	-63.3	-10.4	-23	-29.4	-14	-17.8	-3.05
1309	58	5	-41.6	-57	-52.7	-7	-11	-19.7	-10.3	-40.1
1339	59	5	-90.4	-9.22	-57.6	-61.6	-18.7	-47.7	-12.4	-175
1369	60	4	-59	-18.1	-32.9	-7.21	-8.31	-63.8	-15.9	-10.6
1400	61	3	-4.93	-4.94	-41.4	-52.4	-2.51	-22.1	-16.5	-34.7
1432	62	2	-56.5	-69.8	-163	-147	-263	-15.8	-23.5	-65.5
1465	63	1	-52.6	-61.9	-15.4	-247	-16.4	-5.97	-66.2	-13.9
1499	64	1	-55.7	-98	-13.7	-128	-4.04	-12.1	-45.7	-25.3
1533	65	1	-79.2	-102	-4.45	-6.12	-25.1	-14.9	-47.3	-13.2
1567	66	1	-44.5	-5.14	-6.75	-10.5	-21.5	-21.2	-53.2	-2.96
1601	67	1	-48.5	-55.8	-61.8	-9.71	-43.9	-451	-26.4	-69.4
Sum of Fluxes (Run) :			-3000.51	-2813.87	-2704.94	-2755.62	-2701.6	-3249.04	-2226.61	-2138.47

Table 5.3. (Continued).

Node #	Column	Row	Fluxes: Run 49	Run 50	Node #	Min. Flux	Max. Flux	Avg. Flux	Flux std. dev.
1	1	14	-3.04	-2.65	1	-3.8	-1.64	-2.952	0.305
22	2	14	-6.03	-5.22	22	-9.52	-5.22	-6.002	0.640
43	3	14	-5.91	-4.87	43	-9.56	-4.87	-5.991	0.657
64	4	14	-5.69	-3.3	64	-7.33	-3.3	-5.788	0.555
85	5	14	-5.35	-10.9	85	-10.9	-4.69	-5.842	0.839
106	6	14	-4.46	-10.9	106	-10.9	-4.46	-5.793	0.848
127	7	14	-8.2	-3.32	127	-8.2	-3.32	-5.740	0.673
148	8	14	-8.18	-4.9	148	-8.18	-4.56	-5.694	0.585
169	9	14	-4.36	-5.29	169	-6.39	-4.12	-5.509	0.386
190	10	14	-5.13	-5.43	190	-8.75	-4.99	-5.576	0.501
211	11	14	-5.3	-5.49	211	-8.71	-3.83	-5.495	0.556
232	12	14	-5.35	-5.5	232	-9.28	-3.97	-5.451	0.642
253	13	14	-5.35	-5.47	253	-9.28	-3.69	-5.382	0.714
274	14	14	-5.31	-5.43	274	-9.93	-3.12	-5.297	0.911
295	15	14	-5.25	-5.37	295	-10.6	-3.06	-5.383	1.259
316	16	14	-5.16	-5.26	316	-10.9	-2.89	-5.595	1.685
337	17	14	-5.04	-5.08	337	-10.8	-2.72	-5.438	1.543
358	18	14	-4.89	-4.84	358	-9.44	-2.51	-4.810	1.305
379	19	14	-4.69	-4.94	379	-8.75	-2.33	-4.684	1.345
400	20	14	-4.44	-5.09	400	-10.8	-2.67	-5.000	1.704
421	21	14	-4.12	-4.88	421	-10	-1.64	-4.405	1.684
442	22	14	-3.71	-4.56	442	-20.7	-1.62	-4.910	3.219
463	23	14	-3.17	-4.29	463	-19	-1.02	-5.527	3.522
484	24	14	-2.97	-3.65	484	-25.2	-0.997	-5.451	4.164
505	25	14	-5.63	-2.72	505	-31.4	-1.16	-8.204	6.357
526	26	14	-8.74	-2.02	526	-163	-2.02	-23.834	28.590
547	27	13	-3.66	-42.1	547	-97.1	-0.351	-18.532	22.887
569	28	13	-18.4	-49.3	569	-173	-0.767	-45.837	48.446
591	29	13	-23.5	-7.14	591	-345	-1.47	-93.052	88.643
613	30	13	-8.53	-197	613	-436	-1.7	-142.744	114.539
635	31	13	-237	-213	635	-786	-8.6	-257.736	177.007
657	32	12	-32.1	-10.5	657	-301	-3.3	-81.462	77.189
680	33	12	-180	-2.85	680	-405	-2.03	-110.678	90.506
703	34	12	-180	-2.35	703	-414	-2.35	-110.049	102.407
726	35	12	-53.5	-214	726	-566	-6.05	-101.626	113.859
749	36	12	-16.2	-253	749	-483	-3.76	-106.887	104.782
772	37	12	-7.12	-73.7	772	-387	-2.73	-99.851	93.547
795	38	12	-92.4	-74.8	795	-328	-1.74	-88.147	74.037
818	39	12	-159	-66.1	818	-440	-0.752	-89.504	88.377
841	40	12	-56	-89.5	841	-480	-2.98	-90.860	92.278
864	41	12	-74.3	-58.9	864	-357	-2.17	-87.446	83.488
887	42	12	-77.2	-91.9	887	-351	-2.92	-85.523	76.438
910	43	12	-206	-110	910	-344	-2.59	-103.566	84.175
933	44	11	-5.03	-43	933	-357	-2.28	-43.313	57.294
957	45	10	-4.81	-2.17	957	-66.1	-0.285	-13.996	14.721
982	46	10	-5.28	-7.72	982	-66.1	-0.253	-14.577	14.598
1007	47	10	-6.2	-44.6	1007	-54.8	-2.22	-15.135	12.650
1032	48	10	-15.5	-59.9	1032	-96.2	-4.84	-27.343	21.885
1057	49	9	-24.8	-0.467	1057	-41.1	-0.467	-16.652	11.976
1083	50	8	-17.6	-11.5	1083	-34.1	-0.392	-8.669	7.665
1110	51	8	-7.51	-8.22	1110	-51.3	-0.908	-11.599	10.946
1137	52	8	-9.82	-1.49	1137	-184	-1.49	-23.900	28.675
1164	53	7	-4.72	-14.8	1164	-40.8	-1.27	-9.625	7.787
1192	54	7	-10.9	-15.4	1192	-166	-2.13	-24.163	28.480
1220	55	6	-8.49	-6.31	1220	-76.9	-2.04	-18.567	15.230
1249	56	5	-3.72	-0.565	1249	-78.4	-0.187	-11.057	13.759
1279	57	5	-3.05	-10.6	1279	-63.3	-0.866	-19.024	17.184
1309	58	5	-40.1	-73.2	1309	-95.1	-3.44	-27.974	19.652
1339	59	5	-175	-67.9	1339	-175	-3.18	-51.425	44.164
1369	60	4	-10.6	-7.12	1369	-294	-3.41	-52.395	61.747
1400	61	3	-34.7	-26.4	1400	-299	-1.19	-49.280	58.957
1432	62	2	-65.5	-19.3	1432	-454	-1.59	-67.842	93.559
1465	63	1	-13.9	-21.4	1465	-247	-0.287	-33.905	49.932
1499	64	1	-25.3	-17.6	1499	-144	-0.323	-39.158	39.798
1533	65	1	-13.2	-4.74	1533	-238	-0.537	-38.388	47.288
1567	66	1	-2.96	-66.8	1567	-280	-0.601	-54.946	57.304
1601	67	1	-69.4	-123	1601	-458	-0.448	-82.542	104.084
Sum of Fluxes (Run) :			-2138.47	-2341.71		-4344.73	-2021.781	-2628.726	425.629

Due
Pre Aug 1
(and Early points
to Sen)

Sutton	KB
LE	Agriservices = Spec
Leland = Agriservices	NC Nurse = Pest Appl
Stoneville = Pioneer	will point if for withdrawal
Leland - Any Haze Mutual Envy very small farm or No Haze last longer	Shipped out under Stoneville Name from Leland site

6 CONTAMINATION CHARACTERIZATION AND EVALUATION

The sampling and analysis performed for the RFI have delineated the extent and concentrations of constituents in soil, groundwater, sediments, and surface waters of the Brandywine Creek. This information and the results of the hydrogeologic investigation provide the basis for defining the source areas, for identifying activities that have contributed to the dissemination of contaminated material, and for describing the migration pathways. Analysis of the data has helped to quantify the amount of contaminants that may discharge to Brandywine Creek.

The concentrations of constituents present on site are typical of industrial areas. The impact on Brandywine Creek, the only potential off-site receptor, is too small to be measured.

The remainder of this section summarizes much of the information contained in previous sections of this report. It places this information in the context of recently published proposed rules for Hazardous Waste Management Facilities (Corrective Action for Solid Waste Management Unit at Hazardous Waste Management Facilities; Proposed Rule, Federal Register, July 27, 1990) hereafter referred to as EPA's Proposed Rule. In particular, it indicates that certain polyaromatic hydrocarbons (PAHs) are present in soil above conservative action levels and that certain volatile organic compounds (VOAs) are present in groundwater above action levels promulgated by USEPA. Exceedence of these action levels does not necessarily require corrective action. However, it does require further evaluation for which a recommended approach is outlined.

6.1 SOURCE AREAS

Although several potential sources were identified as part of the records search, only two sources have been confirmed by this investigation. The primary source area for volatile compounds and PAHs appears to be the former burning area near Building 311. The secondary source is along Creek Road where ash from the burning ground was most likely used as fill material when the former Building 255 was demolished and removed sometime between 1948 and 1955. Samples of soil in the vicinity of the former burning ground were consistently high in concentrations of PAHs and volatiles relative to other areas of the site. More convincingly though, the highest concentrations of volatile compounds in groundwater occur below areas between the burning ground and the creek.

Fill material used for roadbeds and parking areas most likely was borrowed from the burning ground area. The types of constituents found in the two areas are similar. Where ash material has been sampled from the fill, its concentrations of PAHs and volatiles are as high as those observed in the burning ground area. The similarity in both the types of contaminants and the concentrations indicates a common source for the burning ground material and the ash in fill areas along Creek Road.

The contaminants observed in soil and groundwater would be expected to be present below an area used for burning spent solvents and other materials. Additionally, residual material from the burning operations would have formed ash.

6.2 EXTENT AND LEVELS OF CONTAMINATION IN SOILS

Detectible levels of PAHs, volatile compounds, pesticides, and metals are present in many of the soil samples. With the exception of PAHs, none of the contaminant classes present any significant concern at the site. Tables 6.1 and 6.2 show maximum concentrations of volatile constituents and metals that have been found in on-site soils. For comparison purposes, those maximum concentrations are compared with action levels set forth in EPA's Proposed Rule. Beryllium and tetrachloroethylene are only slightly above the action levels. Because these levels are based on the maximum observed concentration, they are not of concern.

EPA has not set action levels for any of the semivolatile components detected on site. However, Appendix E of the Proposed Rule provides a method for calculating the action level of a carcinogen if the Oral Slope Factor is known. From the IRIS data base, the slope factor for benzo(a)pyrene is 11.5 $(mg/kg/d)^{-1}$. Using EPA's methodology, an action level of 0.6 mg/kg is obtained for benzo(a)pyrene. Several of the soil samples exceed this action level. The maximum concentration of benzo(a)pyrene is 27 mg/kg.

Table 6.1. Maximum concentrations of volatile organic compounds detected in soil samples.

Constituent	Max Value	Location	Action Level[1]
1,1,1-Trichloroethane	55	f-4a	700,000
1,1,2-Trichloroethane	160	c-2	100,000
1,1-Dichloroethene	240	c-2	8,000
Acetone	94	k 2	8,000,000
Acrolein	4	tbl2/14	--
Acrylonitrile	5	tbl2/14	1,000
Carbon disulfide	1	k-2	8,000,000
Chloroform	34	e-2	100,000
Ethylbenzene	190	c-2	8,000,000
Methylene Chloride	720	c-2	90,000
Tetrachloroethene	13000	c-2	10,000
Toluene	290	c-2	20,000,000
Trans-1,2-Dichloroethene	4000	c-2	--
Trichloroethene	30000	c-2	60,000
Xylenes	1	k-2	200,000,000

***Note: chemicals never found above detection are not included here.

[1] Federal Register, Appendix A, Volume 55, No. 145, July 27, 1990

Table 6.2. Maximum concentrations of metals detected in soil samples.

	Max Value	Location	Action Level[1]
Arsenic	18.4	tp-6:3′	80
Barium	154	k-2	4000
Beryllium	0.41	tp-2a	0.2
Cadmium	3.8	tp-2a	40
Chromium	49.4	m-comp	400
Cobalt	19	tp-6:3′	--
Copper	173	k-2	--
Lead	73.5	k-2	--
Mercury	3	tp-2a	20
Nickel	30.1	k-2	2000
Selenium	0.68	tp-7b	--
Silver	2.21	k-2	200
Vanadium	57.3	tp-7b	--
Zinc	165	k-2	--

***Note: metals never found above detection are not included here.

[1] Federal Register, Appendix A, Volume 55, No. 145, July 27, 1990

fill

The occurrence of the soil contamination correlates with (1) the presence of ill material that includes ash, and (2) the location of former burning ground. The majority of the fill material is covered by pavement. In fact, each of the samples containing more than 10 mg/kg of total semivolatiles was obtained from a sample site covered by pavement.

6.3 EXTEND AND LEVELS OF CONTAMINANTS IN GROUNDWATER

Groundwater below the site contains volatile compounds at concentrations that exceed action levels in EPA's Proposed Rule and exceed MCLs. The highest concentrations occur in the area between the former burning ground and Brandywine Creek. The relatively high concentrations in this area point to the former burning ground as the source area. The lack of significant concentration of volatiles in the two wells upgradient of the former burning ground further confirms the source identification.

Other constituents detected in groundwater include low levels of biphenyl, biphenyl oxide, thalates, lead, zinc, and 1-2dichlorobenzene. None of these constituents occurs above the levels of concern.

The maximum volatile concentration observed was 7700 ug/1 of trichloroethene. The MCL for this constituent is 5 ug/1. The MCL is based on the assumption that the groundwater will be used for drinking purposes. However, groundwater at the site is in a thin, low-yielding water-bearing strata and, therefore, cannot be used for drinking purposes.

6.4 EXTENT AND LEVELS OF CONTAMINANTS IN SEDIMENTS AND SURFACE WATER

No contaminants were detected in the samples of surface water. Only methylene chloride was reported above detection limits. However, methylene chloride also was reported for blanks, thus the results are not reliable.

Sediment samples contain low levels of volatile compounds, biphenyls,biphenyl oxide, and metals. The volatile compounds are observed in areas that would receive surface drainage and groundwater discharge from the former burning ground area. The highest levels of metal are found in the sample taken at the western edge of the study area (Station 2). Beryllium is the only metal that exceeds the soil action level set forth in EPA's Proposed Rule.

The lack of detectible levels of contaminants in the surface water confirms that discharge of groundwater from the site has no impact on water quality in Brandywine Creek. The analysis presented in Section 5 indicated that the flow of groundwater discharge in the study area is 1/10,000 that of the average creek flow. The quantity and levels of contaminants found in groundwater below the site are so low that they can not be detected in the Brandywine Creek.

6.5 RECOMMENDATIONS BASED ON FINDINGS

The soil, groundwater, and sediment data indicate concentrations at a number of sample sites are above action levels set forth by EPA in its Proposed Rule. The action levels in each case are based on conservative assumptions that do not necessarily apply at the Experimental Station Facility. Nonetheless, the Proposed Rule suggests that a Corrective Measures Study (CMS) will be necessary for the site.

Based on the data collected during the RFI, the CMS should focus on the following issues and concerns:

(1) Realistic exposure scenarios should be considered to establish health-based criteria for remedial action. This is particularly true for paved soils where access is restricted.

(2) Beryllium was 40 times higher than EPA's action level for soils in one of the sediment samples. This station should be resampled. If confirmed, the source of the beryllium should be determined. The extent and risk posed by beryllium in the sediments should be defined.

(3) Depending on the results of the first two activities, the feasibility of alternative remedial actions should be assessed. The actions could include vacuum extraction, groundwater pump-and-treat, soil capping, soil removal and disposal at an approved facility, and institutional controls to prevent exposure.

If a CMS is to be conducted, a plan must be developed for EPA's review and approval.

7 REFERENCES

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ES-3178 REV. 8.88

DU PONT
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E. I. DU PONT DE NEMOURS & COMPANY
INCORPORATED
WILMINGTON, DELAWARE 19880

CENTRAL RESEARCH & DEVELOPMENT DEPARTMENT
EXPERIMENTAL STATION

September 20, 1990

Mr. Robert Stroud
U. S. Environmental Protection Agency
Region III
841 Chestnut Building, 3HW61
Philadelphia, PA 19107

Reference: RCRA Facility Investigation (RFI)
Du Pont Experimental Station

Dear Mr. Stroud:

Enclosed please find four copies of the Draft Final Report of the RCRA Facility Investigation (RFI) conducted at the Du Pont Experimental Station, Wilmington, Delaware. The report consists of three volumes that contain the findings of the investigation and all supporting documentation. The final report will be submitted after receipt of EPA's comments.

If you have any questions, please do not hesitate to call.

Sincerely,

Harry J. Dorsman

Harry J. Dorsman
Sr. Staff Environmental Engineer

HJD: bas

Enclosures

cc: C. Chien
K. R. Weiss
Delaware Natural Resources
and Environmental Control

GeoTrans, inc.
GROUNDWATER SPECIALISTS

September 18, 1990

Mr. Harry J. Dorsman
E.I. du Pont de Nemours & Co., Inc.
Experimental Station
P.O. Box 80315
Wilmington, DE 19898

Reference: GeoTrans Project No. 8788-000
RCRA Facility Investigation

Dear Mr. Dorsman:

Enclosed please find eight copies of the Draft Final RFI report to be submitted to EPA and the DNREC. Each report consists of three volumes. I also have sent two copies to Dr. Calvin Chien. Attached is a cover letter that should accompany the reports submitted to EPA after it has been retyped on DuPont's letterhead and received your signature. Four copies of the report are due to Mr. Robert Stroud by Friday, September 21, 1990.

If you have any questions, please do not hesitate to call.

Sincerely,

Lisa L. August
Senior Hydrogeologist

LLA/js
ENCLOSURES

cc: C. Chien
C. Faust
C. Hsu

250 Exchange Place, Suite A, Herndon, Virginia 22070 USA
703/435-4400 • FAX: 703/435-5487

ES-3497 REV 2/87

DU PONT EXPERIMENTAL STATION REQUEST FOR SHIPPING

S.R. NO. ____________

DATE ____________

PLEASE SHIP THE FOLLOWING:

PRODUCT NAME ____________ CHEMICAL NAME ____________

SHIP TO: ____________

STREET ____________

ATTN: ____________

CITY ____________ STATE ____ ZIP 19107

DU PONT CHARGE ACCOUNT

GL ____________

SUB ACCT. ____________

WO ____________

HAS MATERIAL BEEN LABELED TO COMPLY WITH RIGHT TO KNOW LAW AND THE TSCA REGS INCLUDING R&D EXEMPTION. ☐ YES ☐ NO

REF. OR RA NO. ____________

HAZARDOUS MATERIALS YES ☐ NO ☐

IF YES COMPLETE CLASSIFICATION BELOW.

CAPITAL EQUIPMENT YES ☐ NO ☐

TAG SERIAL NO. ____________

CHECK HAZARD CLASSIFICATION, ASTERISK SECONDARY CLASSIFICATION
(SEE REVERSE SIDE FOR DEFINITIONS)

EXPLOSIVES CLASS A ☐, B ☐, C	☐	OXIDIZER	☐
ETIOLOGIC AGENT	☐	FLAMMABLE SOLID	☐
ORGANIC PEROXIDE	☐	CORROSIVE MATERIAL (LIQUID)	☐
RADIOACTIVE MATERIALS (**)	☐	POISON B (LIQUID)	☐
POISON A (GAS)	☐	POISON B (SOLID)	☐
POISON A (LIQUID)	☐	CORROSIVE MATERIAL (SOLID)	☐
FLAMMABLE GAS	☐	IRRITATING MATERIAL	☐
NONFLAMMABLE GAS	☐	COMBUSTIBLE LIQUID (*)	☐
FLAMMABLE LIQUID (*) (BELOW 100°F)	☐	(BETWEEN 100°F & 200°)	☐

(*) FLASH POINT - TAG. C.C. ______°F. LIMITED QUANTITY ☐

(**) SHIPMENT MUST BE APPROVED BY THE RADIOLOGICAL SAFETY OFFICER, PHONE 2147

MATERIALS WHICH COULD POLYMERIZE OR DECOMPOSE IN TRANSIT ARE PROHIBITED

SPECIAL INSTRUCTIONS ____________ VALUE ____________

TO THE BEST OF MY KNOWLEDGE THE INFORMATION ABOVE IS CORRECT.

SIGNED ____________ BLDG. ______ RM. 220 ______ EXT. ______

APPROVED ____________ BLDG. ______ RM. ______ EXT. ______

DO NOT WRITE BELOW THIS LINE

NO. OF PKGS. AND ____________ WT. ______

DESCRIPTION ____________ WT. ______

DATE SHIPPED ____________ WT. ______

VIA ____________ WT. ______

LABELS ____________ WT. ______

S.I.D. NO. FNJD ____________ TOTAL WT. ______

SCHEDULE B NO. ____________ RESTRICTED ART CERTIFICATION PASS OR CARGO AIRCRAFT XRG FORM POST OFFICE FORMS: 2976 2966A 2966 2972

ISSUE ROC ______ ROM ______ REASONS WE CANNOT SHIP ____________

PACKER ____________

ES-3497 REV 2/87

DU PONT EXPERIMENTAL STATION REQUEST FOR SHIPPING

S.R. NO. ______

DATE ______

PLEASE SHIP THE FOLLOWING:

PRODUCT NAME ______ CHEMICAL NAME ______

SHIP TO: ______

STREET ______

ATTN: ______

CITY ______ STATE ______ ZIP ______

DU PONT CHARGE ACCOUNT

GL ______

SUB ACCT. ______

WO ______

HAS MATERIAL BEEN LABELED TO COMPLY WITH RIGHT TO KNOW LAW AND THE TSCA REGS INCLUDING R&D EXEMPTION ☐ YES ☐ NO

REF. OR RA NO. ______

HAZARDOUS MATERIALS YES ☐ NO ☐

IF YES COMPLETE CLASSIFICATION BELOW.

CAPITAL EQUIPMENT YES ☐ NO ☐

TAG SERIAL NO. ______

CHECK HAZARD CLASSIFICATION, ASTERISK SECONDARY CLASSIFICATION
(SEE REVERSE SIDE FOR DEFINITIONS)

EXPLOSIVES CLASS A ☐, B ☐, C	☐	OXIDIZER	☐
ETIOLOGIC AGENT	☐	FLAMMABLE SOLID	☐
ORGANIC PEROXIDE	☐	CORROSIVE MATERIAL (LIQUID)	☐
RADIOACTIVE MATERIALS (**)	☐	POISON B (LIQUID)	☐
POISON A (GAS)	☐	POISON B (SOLID)	☐
POISON A (LIQUID)	☐	CORROSIVE MATERIAL (SOLID)	☐
FLAMMABLE GAS	☐	IRRITATING MATERIAL	☐
NONFLAMMABLE GAS	☐	COMBUSTIBLE LIQUID (*)	☐
FLAMMABLE LIQUID (*) (BELOW 100°F)	☐	(BETWEEN 100°F & 200°)	☐

(*) FLASH POINT - TAG. C.C. ______°F.

LIMITED QUANTITY ☐

(**) SHIPMENT MUST BE APPROVED BY THE RADIOLOGICAL SAFETY OFFICER, PHONE 2147

MATERIALS WHICH COULD POLYMERIZE OR DECOMPOSE IN TRANSIT ARE PROHIBITED

SPECIAL INSTRUCTIONS ______ VALUE ______

TO THE BEST OF MY KNOWLEDGE THE INFORMATION ABOVE IS CORRECT.

SIGNED ______ BLDG. ______ RM. ______ EXT. ______

APPROVED ______ BLDG. ______ RM. ______ EXT. ______

DO NOT WRITE BELOW THIS LINE

NO. OF PKGS. AND	1 CTN PRINTED MATTER	WT. 13
DESCRIPTION	NOT REGULATED	WT.
DATE SHIPPED	9-21-90	WT.
VIA	TOP PRIORITY	WT.
LABELS	LARG	WT.
S.I.D. NO. FNJD		TOTAL WT.

SCHEDULE B NO. ______ RESTRICTED ART CERTIFICATION PASS OR CARGO AIRCRAFT XRG FORM POST OFFICE FORMS: 2976 2966A 2966 2972

ISSUE ROC ______ REASONS WE CANNOT SHIP ______

PACKER ______

ALT. NO.	DISTRIBUTION	DATE
16	4 - LEO CURRIEN 2 - F.O. DOUGHTY 1 - C.F. DONELLY, T.L. BARTELSON, R.E. ROBBINS, W.S. CARELL, J.L. NURNBERG.	2-5-59
17	Same as above	2-16-59

PRINTS ISSUED

17	2-12-59	ADDED OUTSIDE SEWER DRAIN INLET FROM CHEM BURNING AREA (FORMER BLDG. 23) AS PER LETTER OF 2-6-59, T.L. BARTELSON TO H.S. WIDDOES	E.D.

NOTES:

ROOF DRAINS FROM BLDGS. DISCHARGE TO BRANDYWINE CREEK

LINE LOCATIONS ARE APPROXIMATE

LEGEND

- MANHOLE
- OUTSIDE CREEK DRAIN INLET
- OUTSIDE SEWER DRAIN INLET
- SANITARY & PROCESS SEWER LINE
- FLASH TANK
- UNDERGROUND CREEK DRAIN LINE
- OPEN FLUME TO CREEK
- OPEN FLUME TO SEWAGE LINE

NOTE:
SMALL "x" PREFIX ON MANHOLE NUMBER DESIGNATES MANHOLE IN PRESENT EXPERIMENTAL STATION AREA

E.I. DUPONT DE NEMOURS & COMPANY
EXPERIMENTAL STATION, WILMINGTON, DE

"CHEM BURNING AREA" REFERENCED ON SITE BLUEPRINT DATED NOVEMBER 19,1974 (LATEST REVISION DATE)
(REFER TO SECTION 2.3 FOR DISCUSSION OF POSSIBLE SOURCE AREAS)

PREPARED BY : L.L.A.	DATE : 7/31/90	PLATE
CHECKED BY : L.L.A.	REVISED :	3
DRAWN BY : B.C.	DRAWING NO : P0788-016/OD/8	

SEWER & DRAINAGE MAP

DWG. NO. ESI-62 NOV. 17, 1948

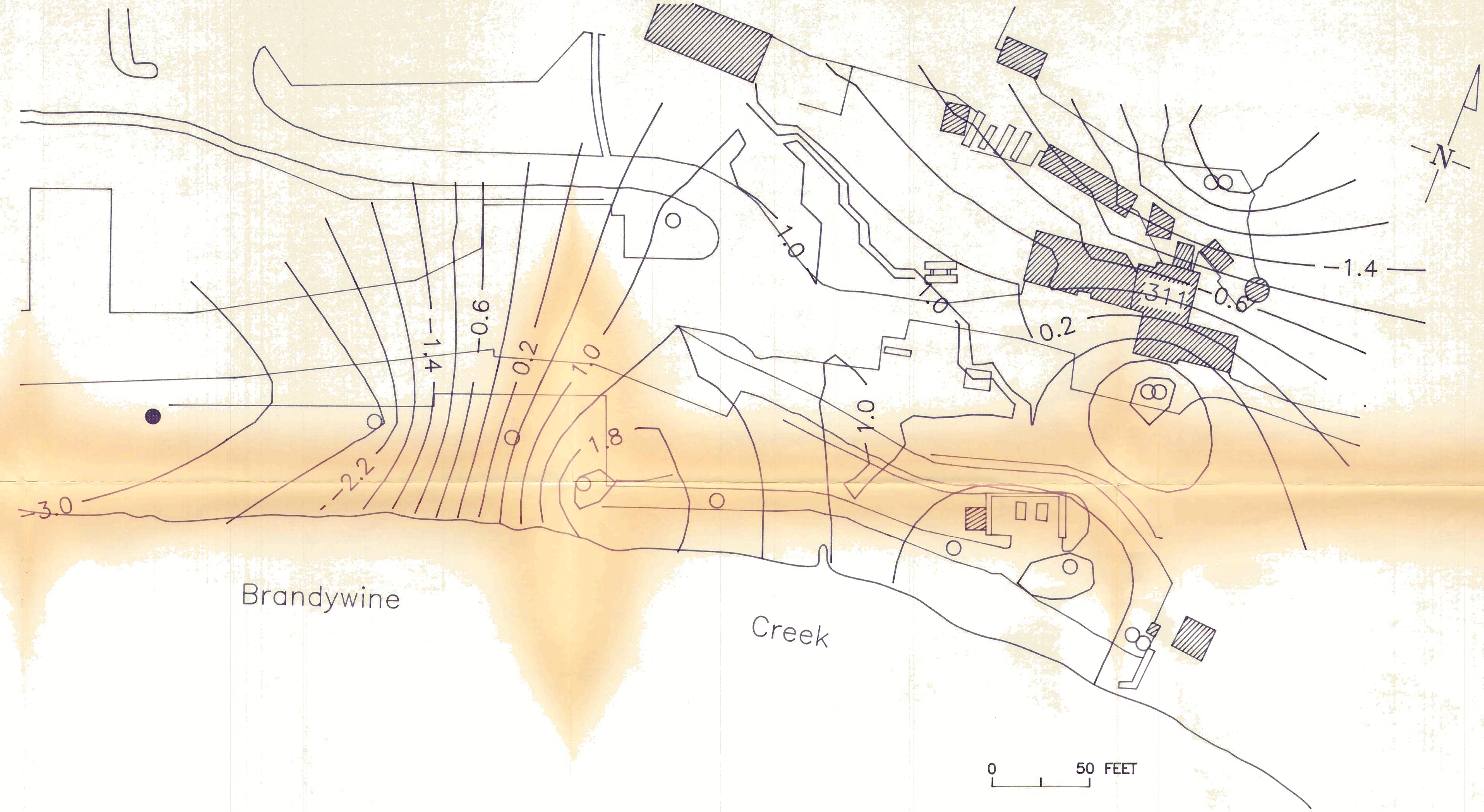
APPROXIMATE SCALE
50' 25' 0 50' 100'

JUL 21 1972

NO.	DATE	REVISIONS	BY	CHKD. BY
21	7/26/61	OUTSIDE SEWER DRAIN INLETS & 4" CONN. LINE	E.D.	
20	3-13-61	BLDG. # 261 REMOVED & SEWER AND SANITARY LINE CAPPED, VALVE IN LINE REMAINS	E.D.	
19	3-13-61	BLDGS. #15, #176 & #248 REMOVED & SANITARY & PROCESS SEWER LINE CAPPED.	E.D.	
18	4-6-59	ADDED SCALE & REMOVED PUMP RM. FLR. DRAIN AS PER LETTER T.L.B. TO H.S.W. 2-17-59 AND CHECK [illegible]	E.D.	
17	2-12-59	ADDED OUTSIDE SEWER DRAIN INLET FROM CHEM BURNING AREA (FORMER BLDG. 23) AS PER LETTER OF 2-6-59 T.L. BARTELSON TO H.S. WIDDOES	E.D.	
16	1-19-59	REMOVED BLDGS. #22, #254 & BOILER HSE. STACK	E.D.	
15	1-14-59	GEN. REVISIONS (SEE CARD INDEX)	E.D.	
14	11-16-59	CUT-OFF & PLUGGED 6" T.C. SANITARY & SEWER LINE FROM BLDG. 109	E.D.	
13	6-13-57	GEN. REVISIONS (SEE CARD INDEX)	E.D.	
12	5-55	ADDED NEW LINE ALONGSIDE BLDG. 248	E.D.	
11	3-7-55	CONNECTED DRAIN LINES REAR OF BLDG. 262	EJS	
10	8-16-55	ADDED 2" GALV. F.O. STEAM-OUT DRAIN, BLDG. 10	E.D.	
9	6-29-55	GENERAL REVISION	EJS	
8	4-7-55	GENERAL REVISION	R.M.C. / E.D.	
7	8-10-53	ADDED LINES AT BLDG. 311	G.E.P.	
6	3-21-53	GENERAL REVISION	C.D.L.	
5	12-5-52	NEW SANITARY LINES ADDED	S.L.T.	
4	12-3-51	ADDED FLASH TANKS & NEW SEWER LINES	M.S.W.	
3	12-3-51	DISMANTLED BLDGS. REMOVED	M.S.W.	
2	10-16-51	ADDED NEW LINE AT #7 BLDG.	W.A.G.	
1	8-1-51	REMOVED DISMANTLED BLDGS.	C.O.L.	

No.	DATE	REVISIONS	BY	CHKD. BY
27	11/19/74	ADDED BLDG. NO. 365 TO OLD POWDER MILL IN LOWER AREA	E.D.	
26	7/6/73	REMOVED SHADING FROM BLDGS 2-6, 173, 2, 174, 257, 272, 268, 251, 249	CAM	
25	7/6/73	REMOVED NOTE - ROOF DRAINS FROM SHADED BLDGS DISCHARGE TO SEWER	CAM	
24	1/3/63	REMOVED BLDGS. #255, 267, 278, & 297 & BROUGHT ROADS AND TANK STOR. UP TO DATE	E.D.	
23	12/5/63	ADD 4" C.I. 6" C.I. OUTSIDE SEWER LINE	[illegible]	
22	7/26/61	8" OUTSIDE SEWER LINE MOVED 1 FT. FOR STEPS & 8" CLEANOUT ADDED TO LINE.	E.D.	

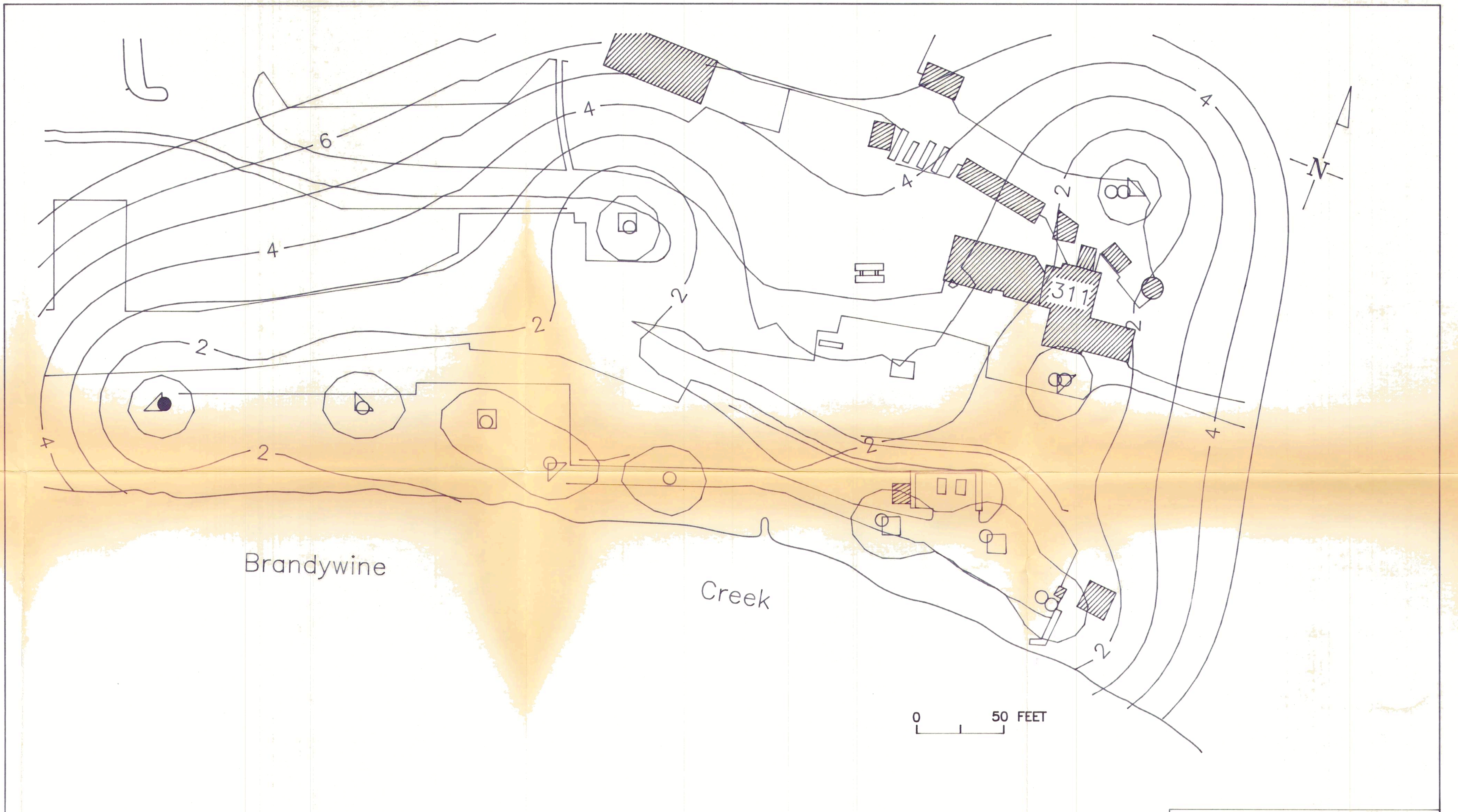
No.	DATE	REVISIONS	BY	CHKD. BY



E.I. DUPONT DE NEMOURS & COMPANY
EXPERIMENTAL STATION, WILMINGTON, DE

CONTOURS OF LOG_{10} TRANSMISSIVITY IN (FT^2/D) FROM KRIGING PROGRAM AKRIP

PREPARED BY: JJB	DATE: 8/15/90	PLATE
CHECKED BY: CRF	REVISED:	5
DRAWN BY: ALH	DWG NO:P8788-016/OC/3	



E.I. DUPONT DE NEMOURS & COMPANY
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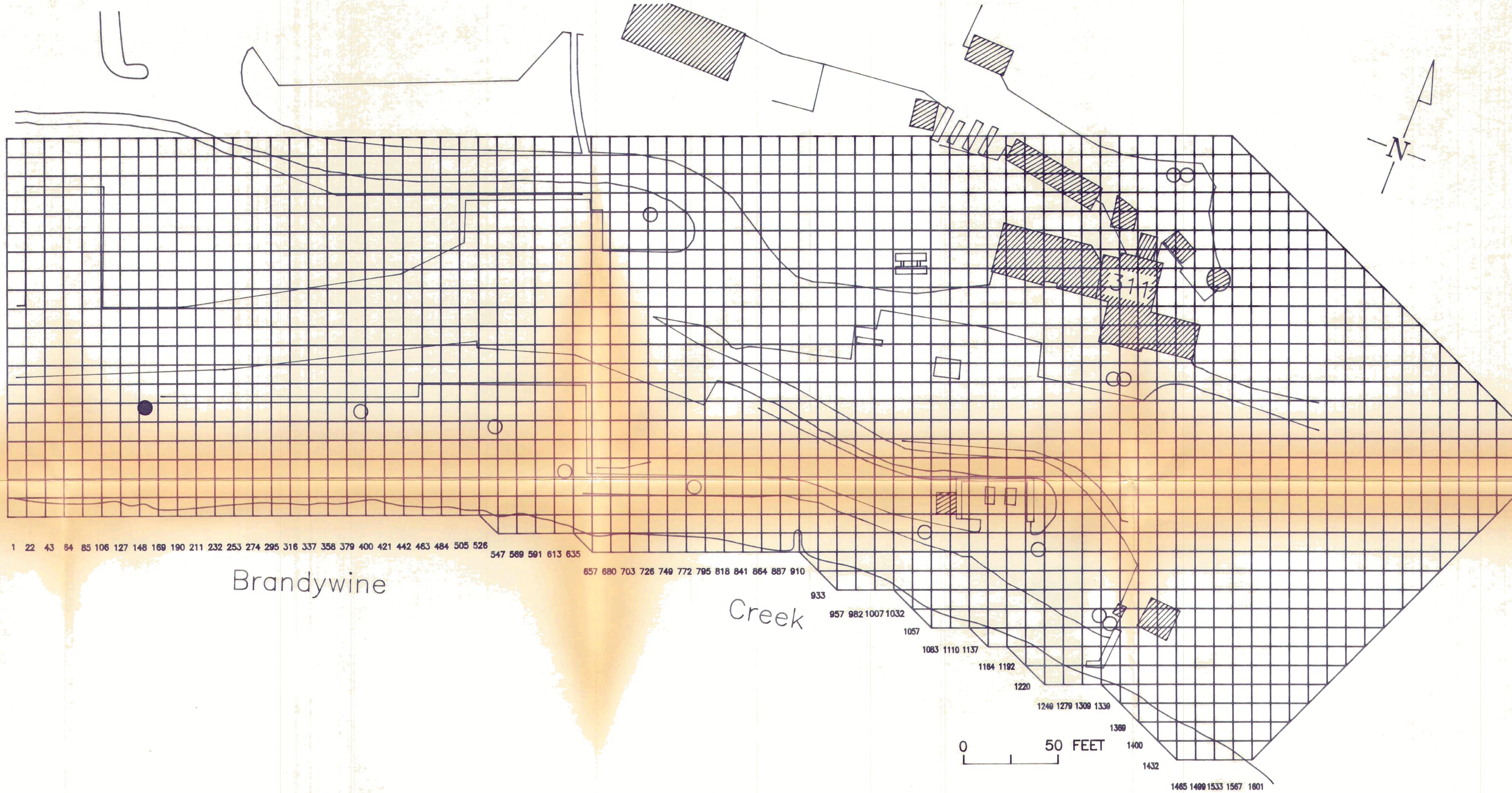
CONTOURS OF THE VARIANCE OF LOG $_{10}$ TRANSMISSIVITY FROM KRIGING PROGRAM AKRIP

PREPARED BY: JJB	DATE: 8/16/90	PLATE
CHECKED BY: CRF	REVISED:	
DRAWN BY: ALH	DWG NO:P8788-016/OC/3	6



E.I. DUPONT DE NEMOURS & COMPANY
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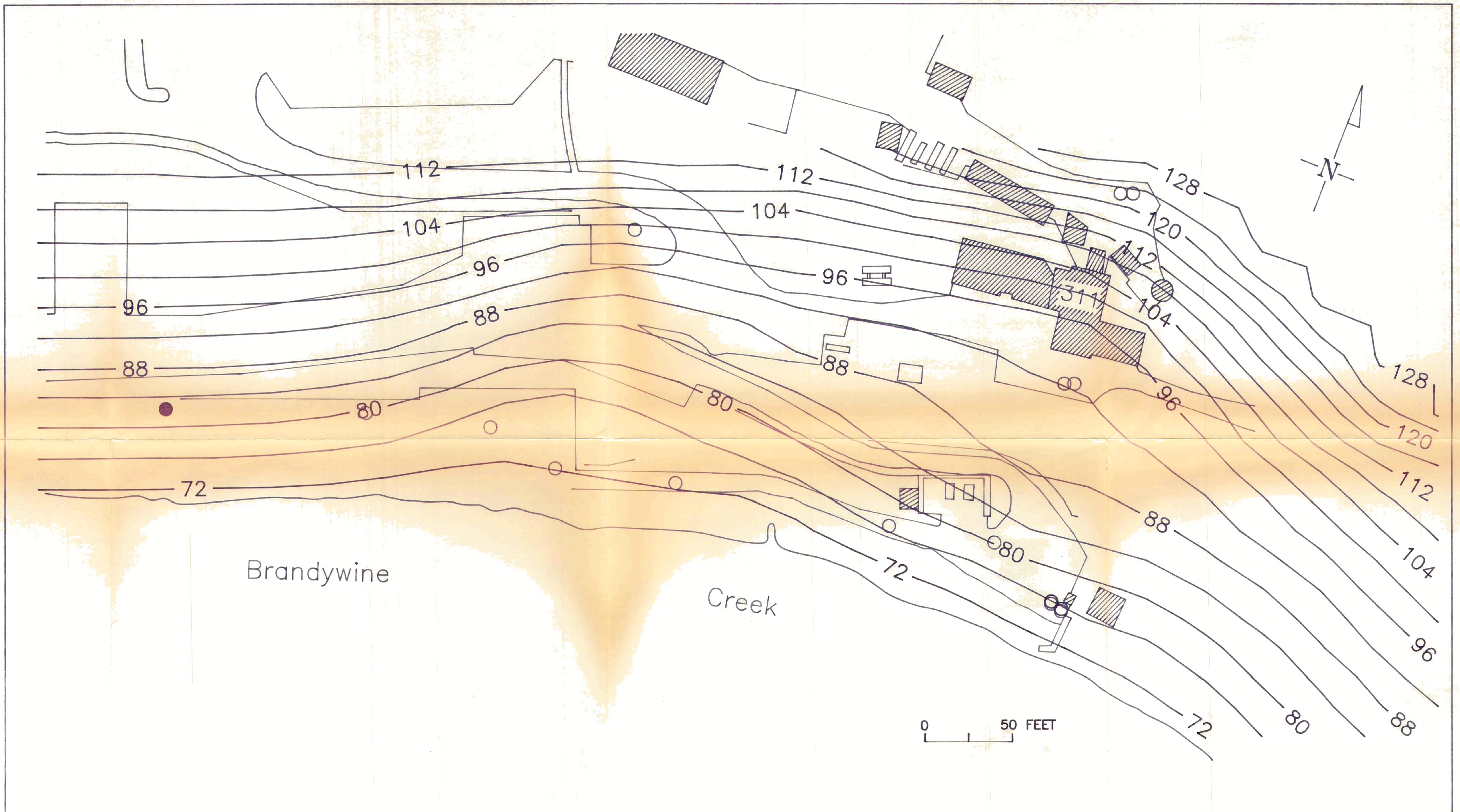
FINITE ELEMENT GRID USED FOR FLOW SIMULATIONS SHOWING THE SITE FEATURES AND NODE NUMBERS ALONG BRANDYWINE CREEK

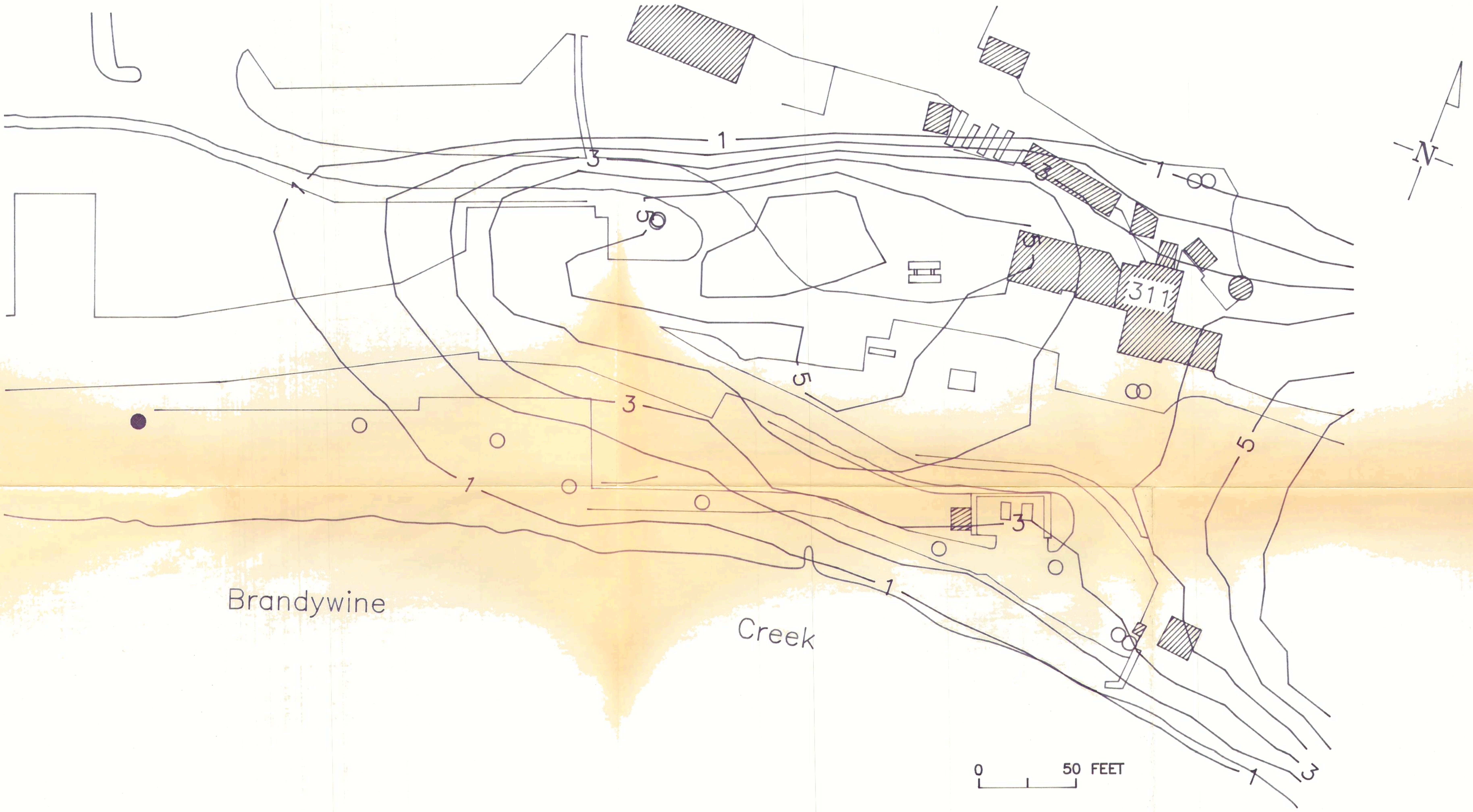
PREPARED BY: JJB	DATE: 8/15/90	PLATE 7
CHECKED BY: CRF	REVISED:	
DRAWN BY: ALH	DWG NO:P8788-016/OC/3	



E.I. DUPONT DE NEMOURS & COMPANY
EXPERIMENTAL STATION, WILMINGTON, DE

GROUNDWATER ELEVATIONS (ft)
AVERAGED FROM 50 MONTE CARLO
FINITE ELEMENT SIMULATIONS

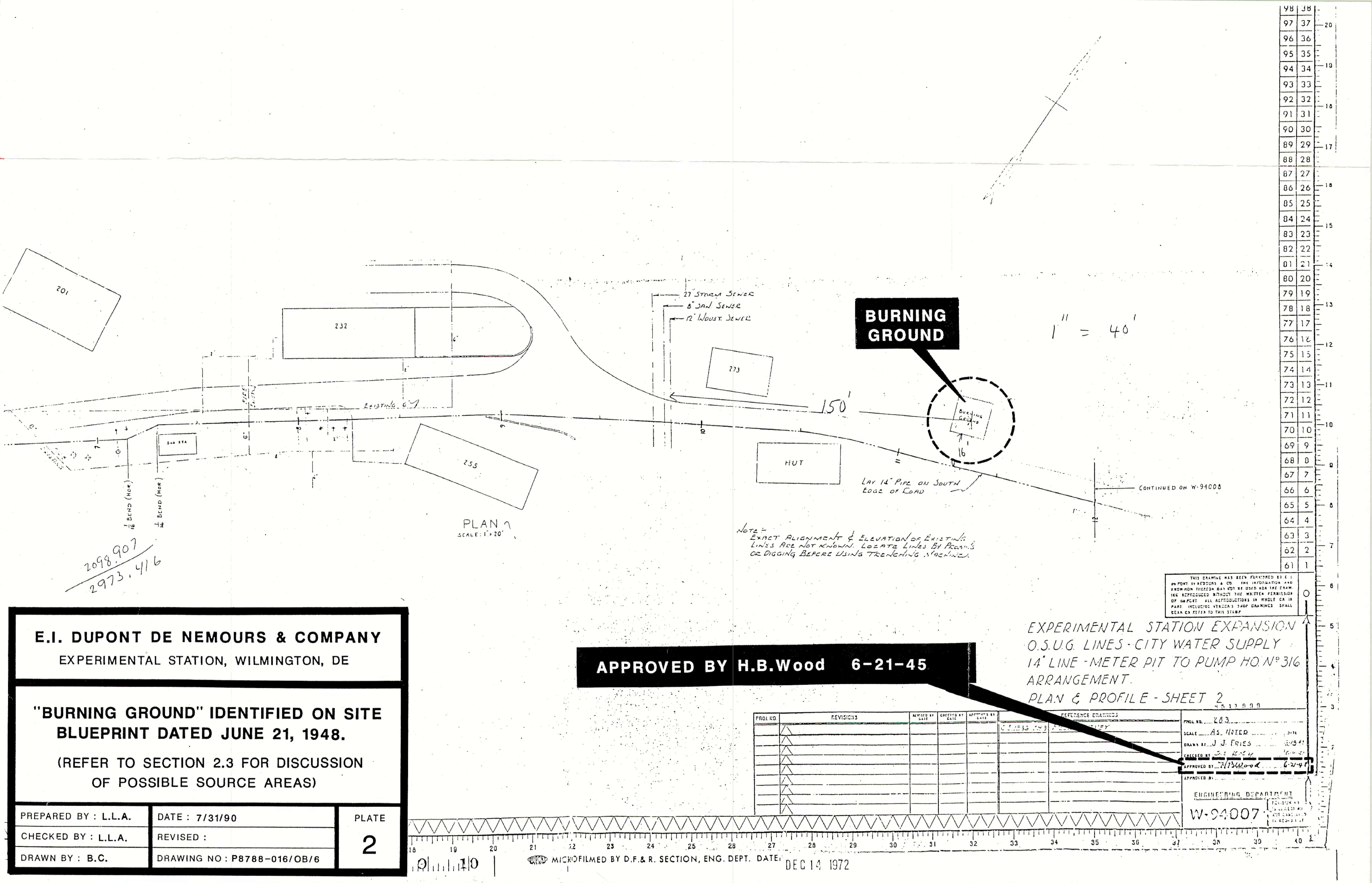
PREPARED BY: JJB	DATE: 8/15/90	PLATE
CHECKED BY: CRF	REVISED:	8
DRAWN BY: ALH	DWG NO:P8788-016/OC/3	



E.I. DUPONT DE NEMOURS & COMPANY
EXPERIMENTAL STATION, WILMINGTON, DE

STANDARD DEVIATION OF GROUND WATER ELEVATIONS FROM 50 MONTE CARLO FINITE ELEMENT SIMULATIONS

PREPARED BY: JJB	DATE: 8/15/90	PLATE
CHECKED BY: CRF	REVISED:	9
DRAWN BY: ALH	DWG NO:P8788-016/OC/3	



E.I. DUPONT DE NEMOURS & COMPANY

EXPERIMENTAL STATION, WILMINGTON, DE

"BURNING GROUND" IDENTIFIED ON SITE BLUEPRINT DATED JUNE 21, 1948.

(REFER TO SECTION 2.3 FOR DISCUSSION OF POSSIBLE SOURCE AREAS)

PREPARED BY : L.L.A.	DATE : 7/31/90	PLATE
CHECKED BY : L.L.A.	REVISED :	2
DRAWN BY : B.C.	DRAWING NO : P8788-016/OB/6	

WELL MW-1B

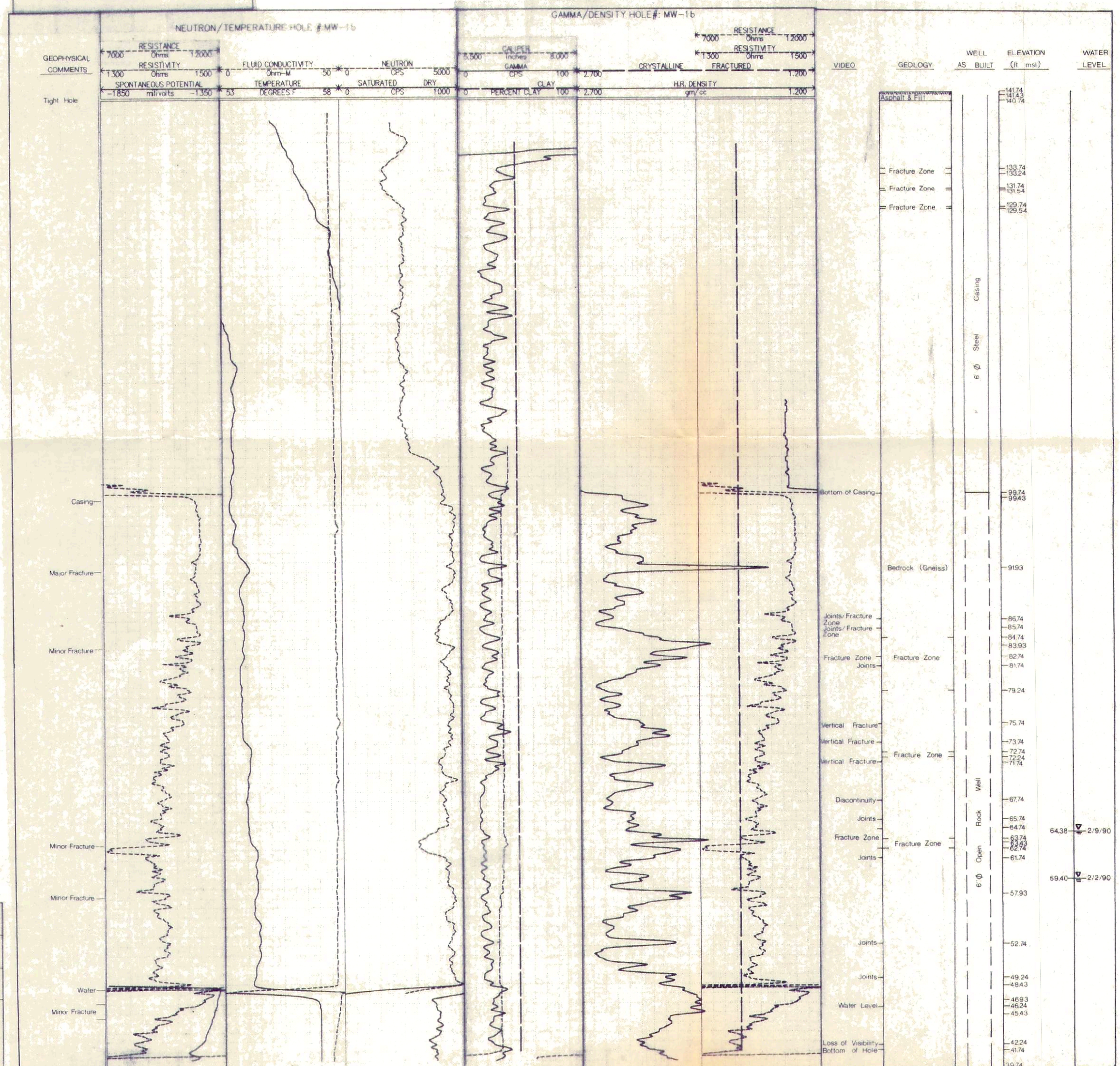
TOTAL DEPTH (ft. below ground surface): 102.0

TOP OF CASING ELEV. (ft. msl): 141.43

HYDRAULIC CONDUCTIVITY (ft./day):

POSITIVE DISPLACEMENT: $\leq 5.9 \times 10^{-5}$

NEGATIVE DISPLACEMENT: Not applicable



WELL MW-2B

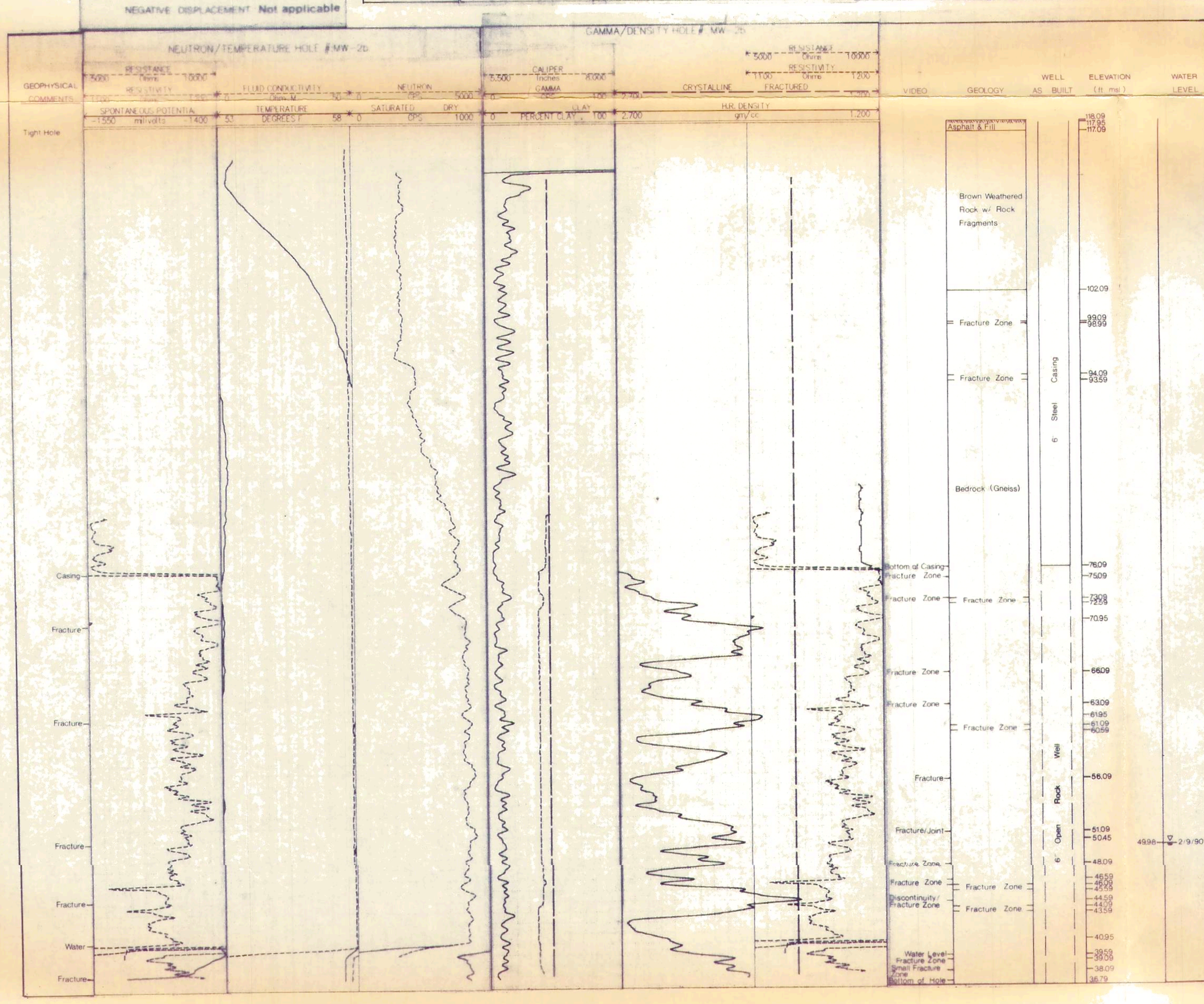
TOTAL DEPTH (ft. below ground surface): 81.3

TOP OF CASING ELEV. (ft. msl): 117.95

HYDRAULIC CONDUCTIVITY (ft./day):

POSITIVE DISPLACEMENT: $\leq 5.9 \times 10^{-5}$

NEGATIVE DISPLACEMENT: Not applicable



E.I. DUPONT DE NEMOURS & COMPANY

EXPERIMENTAL STATION, WILMINGTON, DE

SUMMARY OF GEOLOGIC INFORMATION COLLECTED AT MONITOR WELLS MW-1B AND MW-2B

PREPARED BY : R.R.R.	DATE : 7/31/90	PLATE
CHECKED BY : R.R.R.	REVISED :	4
DRAWN BY : D.T.	DRAWING NO : P8788-016/OC/1	